LESSONS
IN
PHYSICS
HIGGINS

Louise Williams

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LESSONS IN PHYSICS

BY

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PREFACE

In preparing this book, particular attention has been given to the choice of subject-matter and the method of presentation. The pupil's point of view has been carefully considered, and facts which are common in his daily experience have been used in explaining the various principles. The explanations themselves have been made with a care which should render them unusually clear and simple. Throughout the text, the author has sought to emphasize the simplicity and reduce the complexity of the subjects, and the pupil is constantly induced to think. In this way he will study to know, which is better than to remember. The use of words has received thoughtful attention; words of special meaning are sometimes explained in the text, and many which are not thus interpreted may be found in the appended glossary.

No course in laboratory work is required. Some simple experiments are described in the text from time to time, and wherever practicable these experiments could be performed at the teacher's discretion. Should a more extended course of laboratory practice be desired, there are many inexpensive manuals, any one of which may conveniently be used in connection with this text-book.

The book is intended not only to present an elementary view of Physics but also to put the pupil on terms

of intimacy with the subject and its practical applications. Reference is constantly made to these applications of the various principles, so that the pupil may be kept interested and may at the same time gain a considerable knowledge of things in his common experience. This feature is enriched by several illustrations of modern appliances; also by a short biographical sketch of men who have made valuable contributions to scientific knowledge.

The author is indebted to Mr. Everett B. Tewksbury, New York Institution for the Blind, New York City, for reading proof of the whole book and for valuable criticisms; also to Mr. Gilbert B. Morrison, Manual Training High School, Kansas City, for reading a portion of the proof. Mr. H. Carrington Bolton of Washington, D.C., has kindly prepared a list of eminent scientists, which appears, slightly amended, at the end of the text. Several corporations have been very courteous in supplying photographs, from which the half-tone plates have been made: General Electric Company, the dynamo; H. K. Porter Company, Pittsburg, Penn., the air locomotive; American Graphophone Company, Bridgeport, Conn., the phonograph; Spencer Lens Company, Buffalo, N.Y., the microscope; and Baldwin Locomotive Works, the steam locomotive. Grateful acknowledgment is also due the publishers, whose painstaking attention to several details has been very helpful and has added much to the worth of the book.

L. D. H.

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LESSONS IN PHYSICS

CHAPTER I

MATTER; SOME OF ITS PROPERTIES

SECTION I

DEFINITIONS

1. Introduction.—In beginning our study of Physical Science we want to know at once what we are going to study. The word *science* does not mean very much to us, perhaps, and we think it is going to be something very new and strange. Much of it will be new, it is true, and a great deal of it will at first seem strange; but after all we shall find that science tells us about very common things, and shall learn many things that we almost knew before. We see many things happening every day, and become so used to them that we forget to wonder *how* they happen or *why*. But for many years men have been seeing these same things; some have stopped to wonder how and why they happen, and have spent their lives trying to answer these questions. As soon as they find out anything new they go on studying it further, till in time we come to know a very great deal through the work of these men.

To show a little more clearly what the scientist does, let us take an example. You see an apple fall, and you know that anything will fall if it is not held up by some support; but did you ever wonder why apples do not fall up instead of down — did you ever ask why they fall anyway? There have been men, however, who have asked these questions, and who have tried to answer them, not by asking some one else, but by studying falling bodies and finding out directly from nature. They see that under certain conditions the same thing always happens. Presently they form an idea as to what makes it happen so. Then they work to prove that their idea is true; and if they can prove it, the fact becomes known as a *law of nature.*

Now all these "laws" are simply statements of how things behave. When a law has been discovered by any one it becomes a part of our general knowledge about things, and is kept in books or in men's minds. So as time goes on and scientists study more and more, new laws and new facts are always being found out. These facts touch upon many of the things which are most common in our lives. Because they are so numerous they are divided into many subjects, — Botany, Physiology, Physics, Chemistry, and others, — each subject giving us all the facts and laws known about that one branch of science. So when we study any science, we study simply the laws and facts which have come to us as the result of attempts to find out as much as possible concerning the things about us. Of the sciences, Physics is perhaps the most general, and it naturally forms a sort of foundation for scientific study.

2. Matter.—In general, physical science treats of *matter* and *energy*. Concerning matter, the particular study of *Physics* deals with such changes as affect its forms and motions, without especial regard to the nature of the material that a body contains. It is now necessary to know what is meant by "matter." Matter means so much and includes so much, that the best way to define it is to say what is matter and what is not. For convenience, then, let us say this:

Matter is anything which occupies space.

It is not necessary that a thing be seen in order that we may call it matter; air, for example, cannot be seen, yet we know that it takes up room. If we push a tumbler, mouth downward, into a dish of water (Fig. 1), the water will rise only a little way in the tumbler, because the air occupies the space and keeps the water out. We can *pour* water into a tumbler because the air is then free to run out as fast as the water runs in.

FIG. 1

It must be understood, then, that when we study about matter, or speak of matter at all, we mean to include all things which take up any room; and that leaves out only a few such things as thought, influence, etc., which so far as we know have no substance.

3. The Three States of Matter.—*Matter is found in three different conditions: as solids, liquids, and gases.* You have seen solid bodies, and liquids are not less

familiar; but very few of the gases can be seen at all, and with those you are perhaps not so well acquainted.

Solids are those bodies which keep the same size and shape unless changed by some outside force. Iron, wood, earth, flour, ice, and wax are solids, and we can name many others.

Liquids tend to keep the same size, but change their shape according to the vessel containing them. We can pour a liquid from one dish to another, and when we do so the body of liquid takes the shape of the dish into which it is poured. Water is the most common of liquids; oil, molasses, alcohol, and benzine are others.

Gases do not keep either their size or shape, but expand without limit. If we want to keep a gas any length of time, it has to be put in a closed vessel. This is because it *diffuses* very rapidly; that is, the little particles get separated from each other and fly far apart. Then they mix with particles of other gases which happen to be near, and so lose their purity. Gases, as a rule, are much lighter than liquids or solids. Most of them are invisible (cannot be seen), because they are transparent and colorless. A few are colored: chlorine is green, bromine reddish brown, etc. Many may be recognized by their odor, as coal gas, illuminating gas, etc. Among the more common gases are air, hydrogen, oxygen, and steam.

Liquids and gases are called fluids, because they will flow.

Some substances are common in two states, and a few in three. Such solids as wax, lead, tar, and sugar are easily melted to liquids; and some liquids, like naphtha,

ether, and alcohol, easily change to gases. When a liquid "evaporates," it changes to a gaseous state. Water gives us a common example of matter in all three states: ice, a solid; water, a liquid; and steam, a gas.

4. Changes of State. — Most substances may be changed from one state to another by heating or cooling. Solids become liquids and liquids become gases when heated; by cooling we change gases to liquids and liquids to solids.

Again, we may take water as a common example of these changes. Heat changes the solid water (ice) to a

Fig. 2

liquid, and if this be heated more it will be changed to the gas, steam. Now true steam is invisible: we know that if a kettle of water boils hard we see a little space at the spout where there seems to be no steam (Fig. 2). That is where the true steam is, however, for what we see is not steam, but very small particles of water.

When the steam pours from the spout it is very hot; but the cooler air soon chills it so that it turns to liquid drops. If we hold a lamp in this vapor, the heat changes the drops to steam again, so that for a space around the flame we see nothing (Fig. 2).

QUESTIONS

1. What is a natural law? Do men make these laws? How are natural laws discovered?
2. Define Physics. What is meant by "matter"?
3. Name the three states of matter. Give an example of each.
4. What is a solid? a liquid? a gas?
5. Why do gases have to be kept in closed vessels?
6. What is a fluid? What sorts of substances are called fluids?
7. How may the state of a body be changed? Name some substances common in two states; one common in three states.

SECTION II

THE COMPOSITION OF MATTER

5. Theories. — A theory is an idea which we have good reason to believe is true, but which has not yet been actually proved. In studying sciences there are found to be many *facts* and *phenomena* (happenings or appearances) which men are not able to explain. But after long study some man may think out an explanation which seems very reasonable, and others perhaps agree that this explanation is probably correct. Still, for one reason or another, it may not be possible to prove the truth of it, perhaps, and so the explanation becomes known as a *theory*.

To show more clearly, let us take an example. It is very evident that we cannot know for a certainty what is the condition inside the earth, since no one can possibly go down more than a mile or so into it; but men suppose it to be solid rock. They find reasons to make them think so, and almost none to make them think it cannot be. Moreover, they find reasons enough to show that it cannot be in any of the other conditions which some have supposed. Therefore they announce the "theory" that the earth is solid rock inside. We cannot be sure of this, and yet we believe it because it seems reasonable.

A moment's thought will show that there are many things besides this which we cannot really *know* about; therefore we shall find many of these theories as we go on in scientific study. But it must be understood that even if they cannot be proved beyond a doubt, theories are not mere guesses: great thinking men have studied and accepted them, and in all cases there are very good reasons for believing them to be true explanations. In a word, a theory is an idea which we may reasonably believe but cannot absolutely prove.

6. The Molecular Theory. — The molecular theory is an attempt to explain the way in which matter is made up. It states, in the first place, that all matter is composed of *molecules*, which are defined as "the smallest particles of any substance which can exist."

These molecules are certainly too small to be seen, even with the strongest microscope; for any substance large enough to be seen can of course be divided and

made into smaller particles. That such particles really exist cannot be doubted, however; for surely there must be a "smallest possible particle" of any body of matter, and a little thought shows that the smallest bit which can be seen must be made up of smaller parts still.

The theory goes on to state that in any substance these molecules are all separate from each other, that there are spaces (called *pores*) between them, and that the molecules are constantly in a state of *vibration* (*i.e.* a trembling motion, to and fro). This is the part which is new, perhaps, and surely much harder to believe. That the molecules are in motion cannot be proved really, but later in our study we shall find that there are very good reasons for thinking so. Therefore let us accept that as one of the statements in a theory, and for the present simply try to remember it.

As for the spaces, or *pores*, it is not hard to show reasons for believing that they exist. Almost any substance, even iron and other metals, will absorb (soak up) a small amount of water if they are placed in a dish of it. In fact, gold, one of the most compact substances we know, will absorb liquid mercury (quicksilver) very readily.

Summing up these facts, we may make the following statement of the molecular theory:

All matter is composed of exceedingly small particles called molecules; these molecules are entirely separated from each other by spaces, called pores, in which they move constantly in rapid vibration.

This theory is accepted by practically all physicists at the present time.

7. States of Matter explained. — With these ideas in mind, a new explanation of the different states of matter at once presents itself. *Solids* may be regarded as those substances whose molecules do not move about freely or change their positions with relation to each other. To explain more fully: suppose *a*, *b*, *c*, *d*, and *e* (Fig. 3) to represent some of the molecules in a solid. Now while these may all vibrate constantly, moving to and fro, none of them, *a* for example, will change its position among the others by traveling to a new place, as *e* for example. It is because their molecules always stay in the same position among the rest that solid substances retain their shape.

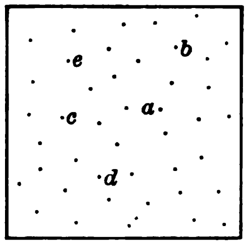

FIG. 3

In *liquids* the molecules tend to keep near together but move freely about, not only vibrating constantly but traveling about each other with great ease. It is because their molecules move about so freely and smoothly that liquids conform to the shape of the vessel which holds them, filling every crevice and corner.

The molecules of *gases* move about freely, as do those of liquids, but they exert no force to keep each other near together. As a result of this, gaseous molecules tend ever to become separated by greater spaces. If a body of any gas be left in an open vessel, its particles will gradually escape, mixing with the air, and their places in the vessel will be filled by air particles.

So we find that in all substances the molecules *vibrate*: in solids they do not change their relative positions of

their own accord; in liquids they change their relative positions easily; in gases they move as freely and tend to become separated from each other without limit. This easy movement of their molecules explains why liquids and gases *flow* readily. And it is the lack of any force to hold their molecules near together that causes gases to *diffuse*, as we have learned.

QUESTIONS

1. What is a theory? How is it different from a mere supposition?
2. State the molecular theory. What is a molecule? What are pores? How may the existence of pores be proved?
3. How does the molecular theory explain the difference between solids and liquids? between liquids and gases?
4. Why do liquids conform to the vessel containing them?
5. Why do liquids and gases easily flow?
6. Why do gases easily diffuse? How may a gas be kept pure?
7. What two sorts of motion may the molecules have?

SECTION III

PROPERTIES OF MATTER

8. Indestructibility. — Though matter occurs in many forms and kinds, it possesses certain features which are common to many or all kinds. Any of these features may be called *properties* of matter. As there are very many such properties, we shall have to confine our study to a few of the more common.

One of the few which apply to all matter is that of *indestructibility*. This long word, as here used, means

simply that *no body of matter can be destroyed.* We may change matter so much that we cannot recognize it, but we cannot destroy anything so that there will be nothing left of it. Wood burns and seems to be lost; yet if we collect all the ashes, smoke, and gas, and weigh them, we shall have just as much as the weight of the wood. Water may "boil away"; but if we collect all the steam and cool it, we shall have as much water as at first.

We cannot make something out of nothing; neither can we take something and make nothing out of it. The rain that falls out of the air had first to get into the air from the earth; and if we boil that water all away it only returns again to the air.

9. Impenetrability. — The statement that "no two bodies of matter can occupy the same space at the same time" is not unfamiliar. It does not mean that one cannot put two books into the same desk or two hands into the same pocket, for in either case both objects do not occupy the *same space.* Even when two liquids or gases seem to unite so thoroughly that they cannot be separately distinguished, each of their tiny particles may be found to occupy its own space alone.

Hold a bottle or tumbler mouth downward in water, as in Fig. 4, and note that the water enters only a little way; turn the mouth sideways (Fig. 5), and the water enters — but not until the air has first run out. If the bottle were held mouth upward, water would run in, as in the second case. When the mouth was downward the air could not escape, being lighter than water.

We have perhaps tried pouring some thick liquid (*e.g.* molasses) into a small-mouthed bottle, with poor success. The thick liquid filled the small opening and

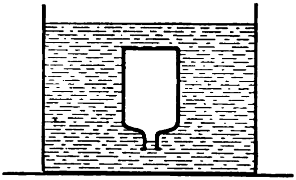

FIG. 4

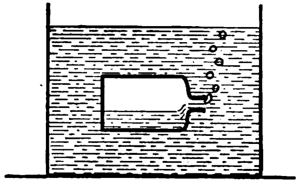

FIG. 5

the air escaped with difficulty. These things show that even a gas must have room; and unless the gas can be removed from a space, other things cannot be crowded into it.

10. Hardness. — The common test of hardness is to scratch one substance with another; the one which will be scratched by the other is the softer. The word *hard* is used often enough by every one, but this subject is one which may bear a little study, nevertheless. Different substances show different degrees of hardness; diamond is very hard, also emery and quartz. Among the softer solids are many which are almost liquid, — wax, vaseline, snow, etc., needing only a little heat to change them. And among the harder substances we may notice that heat, which would in time liquefy them, serves to soften. A blacksmith *heats* the iron before he beats it into shape. So we see that hardness is a property of solids, and that as a solid approaches the liquid state it grows softer. This suggests at once that hardness and solidity have some relation. We have learned that in solids

the molecules do not change their relative positions. But they can be made to do so by some *outside* force. When a substance can be easily forced and pressed into a different shape, we say it is soft; and the more a substance resists such a change of shape, the harder it is said to be. Therefore we may say that *hardness is due to the resistance made by the molecules to a change of relative position;* the greater such resistance, the harder the substance.

Hardening. It often happens, in mechanical uses, that men desire to cut, bend, or mold a substance while it is soft, and then make it harder afterward. For example, a file could not be cut or a spring bent into shape if it were hard; on the other hand, neither would be of any use if it were soft. Plainly the metal must be cut or shaped while soft, and hardened later. This may be done by heating the metal to an intense degree and then throwing it quickly into water. In some way the sudden cooling seems to fix the molecules more firmly in their position, so that they offer more resistance to being changed. The process is called *case hardening, hardening*, or *tempering.* In finer grades of work, such as tempering springs or hardening files, oil is used instead of water.

A hard substance may, in some cases, be made soft or *flexible* by heating it to a high degree and allowing it to cool slowly in air. This process is called *annealing*, or, by some, "drawing the temper." Should a file, for example, wear out, it could be softened in this manner and again cut; similarly, old springs may be softened, bent, and tempered anew.

11. Cohesion. — *Cohesion is the force which holds all the molecules of a body together.* The particles of some matter have much greater cohesive force than do others; such substances are much harder to break than others, and we say they are *tough.*

The cause of toughness is very similar to that of hardness; yet there is a difference which may require some thought to discover. A body is "tough" when it cannot easily be broken. Many a "hard" substance is *brittle*, and may be very easily broken, — glass, for example. Cast iron is harder than pure iron, yet not nearly as tough. We have learned that cohesion is the cause of toughness, and cohesion is defined as the force which holds the molecules together; while hardness is due to the resistance offered by a molecule to any change of relative position. It is perfectly possible for the molecules of a body to *change their relative positions* easily and yet offer great resistance to *being separated;* also the molecules of another substance may easily be separated, but resist any force which would change their relative positions. The first substance would be called *soft and tough*, while the second would be *brittle and hard.*

Regarding cohesion, the question may naturally arise: Why, if this force exists between molecules, can we not mend a broken body by holding the broken surfaces together? Simply because they cannot be forced near enough to each other. It must be remembered that the molecules are very small, and that the spaces between them are also small; force the ends together as hard as may be by simple pressure, the distance between them will still be too great for the cohesive force to be felt.

In some cases, however, the thing may be done by using heat. A blacksmith, for example, heats two pieces of iron till they are fairly soft, and then by much pounding with a heavy hammer he forces the parts together. This process is called *welding*, and it is possible because the iron is softened by heat.

Viscosity. Many solid substances (*e.g.* sealing wax) which do not easily change their shape may be bent or pressed into a lasting change of form if force be exerted upon them for a long time. Such substances are said to be *viscous*.

12. Adhesion. —*Adhesion is the force which holds the parts of one body to those of another.* If we balance a flat piece of glass, *a* (Fig. 6), with weights on the pan *b*, and then lower *a* till it just touches the surface of water, we shall have to add several more weights to *b* before the glass will be lifted from the water. The extra weights give the measure of the *adhesive force* of the water for the glass. Drops of water often cling to the bottom or sides of a glass vessel by adhesion.

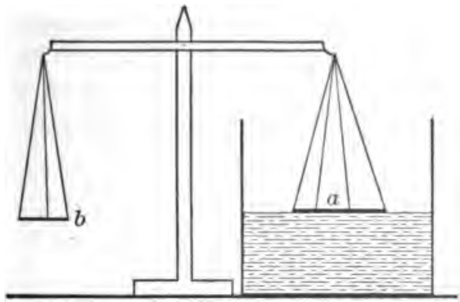

FIG. 6

All substances do not have this adhesion for all others. In most cases it is necessary to use some third substance, like paste, glue, etc., which will adhere to both bodies and so hold them together.

13. Elasticity. — *Elasticity is that property which a body has when it resumes its former shape or size as soon as the cause which changed it has been removed.* We call rubber elastic, not because it may be stretched very much, but because it snaps back to its first shape and size when we let go. Some substances which cannot be bent or stretched nearly as much as rubber are yet more elastic, for rubber in time loses its power to return to its first condition.

This property of matter is very important, and we must consider it carefully. Think of the watches, clocks, and other machinery which are run by springs. It is only the elasticity of the spring which makes it

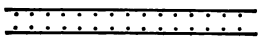

FIG. 7

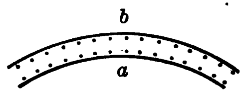

FIG. 8

unwind and set the machinery in motion. *Gases are elastic* also; that is, when they have been pressed into a small space they exert force and try to expand to their original volume. Compressed air is simply a large amount of air pressed into a small space; being elastic it tries to expand, and in so doing it exerts force. This force is sometimes used by man and may do much work; for example, the air brakes on trains are applied by the elastic force of compressed air.

Like hardness, cohesion, etc., *elasticity* may be explained by the molecular theory. Let Fig. 7 represent an elastic rod, and Fig. 8 the same rod bent; in each figure suppose the spots to represent molecules. A glance at the bent rod shows that on the side *a* the

molecules are crowded nearer together, and on the side *b* they are stretched farther apart, than their usual position in the straight rod. The rod is said to be in a state of *tension:* the molecules at *a*, being crowded, tend to separate; while those on the other side, being separated more than usual, tend to draw each other closer. Thus we see two forces tending to straighten the rod, and as soon as the force which bends it is released they will act and cause the rod to assume its former shape. In a similar way this explanation may be applied to other elastic bodies.

14. Crystallization. — This property of matter is perhaps not quite so familiar, by name at least. You have seen snowflakes, however, and have doubtless watched the frost form in beautiful figures on a window. The snowflakes and the frost are only water in the form of *crystals.* You have seen diamonds and other precious stones; did you ever notice their form? Each kind has a different shape, but all the stones of the same kind have the same shape. The diamond, ruby, emerald, garnet, etc., are crystals. But what is a crystal?

FIG. 9

Dissolve some alum in hot water till the water will no longer take it up. Then hang a string in the water (Fig. 9) and let it stand. In a few hours we shall find crystals of alum on the string and sides of the glass. Crystals, then,

sometimes form when a solution is cooled. Melt some sulphur, cool it slowly, and crystals will form.

Now a crystal of water is only water, a crystal of alum is still alum, and sulphur crystals are little different. A crystal, then, is only a peculiar *form* which some substances assume when they are slowly cooled from a liquid to a solid state. Each substance makes a certain shape of crystal every time, though of sizes there may be a great variety. This property of matter is also important, and is used by man in many ways. Sugar, for example, is made by heating the juice from the cane or beet till it is thick; when it cools, the sugar settles to the bottom as small white crystals.

Just what causes some substances to form these crystals we cannot say. It seems to be a power which the molecules possess; and if man wants to make a substance crystallize, the best he can do is to supply the conditions (heat and slow cooling) and leave it to the molecules themselves to do the work of arrangement. How it is done, or why, are questions we cannot answer. We can only say it is one of the properties of many kinds of matter.

QUESTIONS

1. What is meant by indestructibility? What becomes of the matter in wood when it is burned? Where does the water go when it "boils away"?
2. How may hardness be tested?
3. Name some hard substances; some soft ones.
4. Does heat tend to make a body generally hard or soft?
5. To what is hardness due?
6. How are springs tempered? How may a hard body be softened?

7. What is meant by impenetrability?

8. What is cohesion? Define viscosity by showing how a viscous body acts.

9. What is the difference between a hard and a tough body?

10. Why can we not mend a broken solid by pushing the pieces into place? How is welding accomplished?

11. What is adhesion? Give illustrations. Do all substances adhere equally well?

12. Define elasticity. Show how gases are elastic.

13. What is a crystal? Name several substances which crystallize.

14. Under what conditions are crystals formed?

SECTION IV

PROPERTIES OF MATTER: GRAVITATION

15. The Law of Gravitation. — We all know these facts: that all bodies near the earth fall to it if they are free to fall; that all bodies on the earth are held on it by some means which we cannot see; and that the earth, the moon, and the planets are all held in place and kept moving about the sun, also by some invisible means. We see at a glance that there must be some mighty power, some great force necessary to accomplish this. And we call this the force of *gravitation.*

But scientific men have gone a step farther, and they tell us that *all* bodies of matter exert this same force, — that *every body of matter in the universe attracts every other body with a certain amount of force.* The strength of this attraction between two bodies increases with the amount of matter in them, and decreases as they are moved farther apart.

The rate of increase and decrease has been measured in many cases, and the result is summed up in the so-called *Law of Gravitation.* The law is as follows:

The strength of the attraction of gravitation between any two bodies of matter varies directly with the product of their masses (quantity of matter), and inversely as the square of the distance between their centers of attraction.

Or, putting it a little more simply, when a body attracts two others, for example, the greater of the two will be drawn by a force as much larger than the other as its mass is times the mass of the lesser. The last part of the law means that as the square of the distance between two bodies increases, for instance, the attraction between them decreases in proportion. In computing the relative attraction of two bodies for a third, of course both *distance* and *quantity of matter* must be considered. Thus we find, for example, that while the mass of the sun is far greater than that of the moon, still the moon's distance is so much less than the sun's that it attracts bodies at the earth's surface more strongly than the sun does. This is shown by the tides, which are governed rather more by the moon's position than by the sun's.

16. Gravity. — We wonder, almost at once, why, if every body of matter attracts every other, all things are not drawn together in one place. The reason is simple. If the strength of attraction increases with the amount of matter, surely the attraction of *the earth* is stronger than that of any body on its surface. Even if two bodies rest on a perfectly level surface, the attraction for the earth will still be so great that they cannot come

together; for in moving towards each other they will rub on the surface hard enough to overcome the weak attraction between them.

The experiment has been made of hanging two heavy iron balls near together from a great height; it was found that they moved towards each other a very little (Fig. 10). In so doing, however, it is clear that the balls must swing up just a little from their lowest position; in other words, the attractive force of each for the other must be great enough to raise them a little way against the force of gravity. For this reason only very heavy masses will so swing toward each other, and even they will not move far from the vertical line.

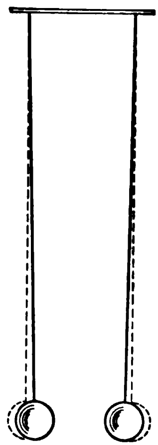

FIG. 10

Now we see why bodies fall: it is because they are *pulled* down by a force. And this force is only one of the "properties" which all matter has in common. The earth, being so much larger and so near, exerts this force more strongly than any other body, so that all things on the earth stay on it or fall toward it when free to fall. When we are speaking of this attraction with reference to the earth, we call it *gravity*. If it were not for this force of gravity, no moving body would remain long on the earth. We should jump up and keep on going, toss up our hats and never see them again. A ball would stay as well beneath a shelf as on top of it; in fact, we should have no need of shelves, for things would stay anywhere.

17. Weight. — In trading and in many other uses, it is often necessary for us to know how much matter there is in a body. This calls for some system of measuring things which is based on the *quantity of matter* in them. The size of a body does not always tell us how much matter there is in it; there is far more matter in a bag of shot, for example, than in a bag of feathers the same size. But nature gives us an easy way of measuring *mass* (quantity of matter). We have learned that the force with which bodies attract each other depends upon the amount of matter in them. Thus we see that the quantity of matter in any body may be measured by the force with which it is drawn to the earth. We call this *weighing* a body.

The weight of a body is the measure of the force with which the earth attracts it. When we say a body weighs one pound, we mean simply that the earth draws on it with a force of one pound. Also we should have to use one pound of force to hold it up.

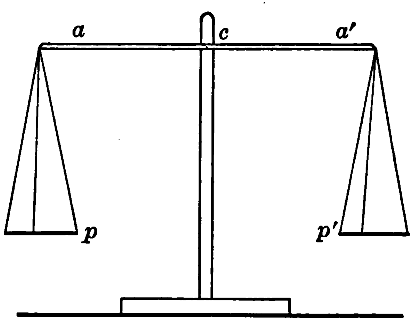

FIG. 11

There are several ways of measuring the force of gravity. We are familiar with ordinary "scales" (Fig. 11). Two arms, *a* and *a′*, of equal weight and length, are balanced on a central point, *c*. If we put a known weight in the pan *p* (say a pound), then we can load the other pan till they balance;

that is, till both pans are on the same level. Then the force of gravity will be pulling just evenly on both pans, and we know there is just one pound of matter in p'.

Such scales as these may be made so that they will weigh very accurately. In many physical and chemical laboratories there are scales so very sensitive that they could measure the difference in weight between a piece of paper before and after you had written on it with a soft pencil.

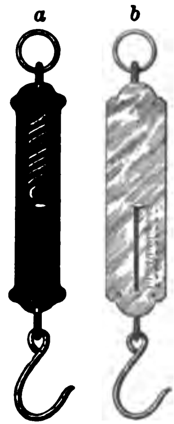

FIG. 12

Another instrument for weighing bodies is the "spring balance" (Fig. 12), more properly called a *dynamometer* (force measure). This works by means of a spring, shown in *a*. A force of one pound pulls the hook down somewhat; a force of two pounds pulls it more, and so on. A little pointer (see *b*) travels down a scale marked on the face of the "balance," and shows how many pounds the hook is holding. Such an instrument measures the attractive force of gravity directly. If we were to weigh a body with one of them, we should find that it weighed a little less on a mountain, because, being a little farther from the center of the earth, the attraction would be a little less.

Note that *all matter has some weight.* Even the lightest gases, such as air, weigh something; for all matter has the power of attracting and being attracted by other bodies, and weight is, as we have seen, simply the measure of this attraction for the earth.

18. Density. — We know that a piece of lead weighs more than a piece of wood the same size; and we know that if it weighs more, there must be more matter in it. Now if a block of lead contains more matter than the same volume (size) of wood, the matter in it must be more tightly packed together; in other words, the lead is *denser* than the wood. So we judge of the density of a body by comparing its weight with other kinds of matter having the same size. For a definition we may say:

Density is the quantity of matter in a body per unit of volume. That is, if we weigh a cubic inch of each of two bodies, the heavier will be also the denser.

19. Weight and Density distinguished. — From the preceding paragraph we learn that density, like weight, is found by measuring the force of gravity upon a body. Yet we must understand that the two have a very distinct meaning. Weight applies to the body as a whole, whereas density applies to the substance or kind of matter of which the body is made. *Weight* is the measure of the force with which a body is drawn toward the earth, while *density* tells us how closely the particles of a body are packed together. In weighing a body simply to measure that force, we make no account of its size; but in weighing a substance to find its density, we have to consider size also.

The weight of a body may vary according to where it is on the earth: on high land it would be less than in a valley or at the sea level (why?), and at the poles of the earth it would be more than at the equator, the poles being about thirteen miles nearer the earth's center.

QUESTIONS

1. What force holds the earth and other planets in place?

2. Do all bodies have power to attract others? Why do not all bodies succeed in attracting others to them?

3. State the Law of Gravitation. Define gravitation.

4. What is a vertical line?

5. What is gravity? Can we avoid the force of gravity on earth?

6. What is meant by weight? Where would you weigh more, on earth or on the moon? in a valley or on a mountain? at the equator or at the north pole?

7. How are bodies weighed? Does air have weight?

8. To what point does gravity tend to pull all bodies? What would happen if gravity ceased to act?

9. Suppose a tunnel straight through the center of the earth: where would a body come to rest if it fell in?

10. Define density. How could we tell which of two substances was denser?

11. State the difference between density and weight.

12. Which would be denser, a body which floats on water or one which sinks?

13. A swimmer finds that salt water holds him up better than fresh water: which is the more dense?

SECTION V

MEASUREMENTS

20. Volume, Mass, and Capacity. — In studying or working with matter or forces, it is often necessary to have some way of expressing quantity or size, that is, some system of measurements. As there are many and various things to be measured and several different ways in which we may measure each, there must of course be several kinds of measurements. One kind, for example, will be used to measure distances; another,

to measure surfaces or areas; another, cubical contents or size; another, weight (force of gravity); another, density; and so on. Distances (that is, measurements in a straight line) are called *linear* measurements. The linear measurements of any solid (that is, its length, width, and thickness) are called its *dimensions*.

The *volume* of a body means the *amount of space which it takes up. Mass* means the *quantity of matter* that a body contains, without regard to the space that it takes up. There is danger of confusing these two, volume and mass, unless great care is used to understand them thoroughly. Volume takes no account of the substance composing a body, or of its weight; only its size, or the amount of space it occupies, is expressed by this measurement. The mass of a body may be determined in different ways; one of the most common of these is to measure the force with which gravity attracts it, at a given level on the earth's surface. *Density*, as has been seen, combines in one expression both the *volume* and the *mass* of a substance. The measurement which determines how much (by volume, usually) any receptacle may hold is called *capacity*.

21. Units of Measurement. — In order to measure anything in any way, we must find how many times it will contain a certain definite quantity taken as a *unit*. Each of the different kinds of measurement must have as a unit some definite quantity having the same nature as itself; for example, linear measurements must use some line as a unit, measurements of volume must employ some cube, and so on. Any person could make

use of any size or quantity he chose as a unit; but for convenience in dealing with others, certain units are determined upon and used commonly by whole nations or groups of traders. When a unit has been fixed by law or common consent, it is called a *standard unit.* The standard units are not the same in all countries nor among all classes of people. Some may be used only in a small locality or among a very few, while others are almost world-wide in their application. For ordinary trading, the system which we use (based upon the pound, foot, and quart) is the standard we have borrowed from England.

22. The Metric System. — The system of measurements which has been adopted by Congress as the standard for this country is the one in use by the French nation. As it is also the system used by all scientific men the world over, we want to give it careful attention.

The name *metric* is applied because the system is based upon the *meter.* This is the unit for linear measurements. Defined by law, it is the distance between two marks (about 39.37 inches) on a bar of platinum at 0° Centigrade. The bar is over one hundred years old, and is carefully kept by the government in Paris. Copies of this rod and other units are kept with equal care in Washington.

Based upon the meter as a unit, we have the following

TABLE OF LINEAR MEASURES

1 millimeter (mm.)	=	0.001 meter (m.)
1 centimeter (cm.)	=	0.01 meter
1 decimeter (dm.)	=	0.1 meter
1 kilometer (km.)	=	1000 meters

Areas of surfaces would be expressed in terms of square meters ($m.^2$), square centimeters ($cm.^2$), and the like.

Measures of *volume* might, in a similar manner, be stated in terms of cubic millimeters ($mm.^3$), cubic centimeters ($cm.^3$ or cc.), etc.

Measures of *capacity* are based upon the *liter* as a unit. In the following table we may note also a relation to the meter, centimeter, and others.

TABLE OF CAPACITY MEASURES

1 milliliter (ml.)	= 1 cubic centimeter ($cm.^3$ or cc.)
1 centiliter (cl.)	= 10 cc.
1 deciliter (dl.)	= 100 cc.
1 liter (l.)	= 1000 cc.

The unit of *mass* is the *gram*. It is equivalent to the mass of one cubic centimeter of distilled water at 4° Centigrade. The gram is one thousandth of the mass of a piece of platinum kept at Paris as the standard of mass measurements, and called a *kilogram*.

TABLE OF MASS MEASURES

1 milligram (mg.)	= 0.001 gram (g.)
1 centigram (cg.)	= 0.01 gram
1 decigram (dg.)	= 0.1 gram
1 kilogram (kg.)	= 1000 grams

In order to become familiar with the system, a few approximate values may serve to give a better idea of some of the measurements. We may fix linear measure by remembering that the *centimeter* is a little less than half an inch, the *meter* a little more than a yard, and

the *kilometer* (which is used as we use the mile) is only about five eighths of a mile. For capacity we may think of the *liter* as being about a quart. The unit of mass, the *gram*, weighs about as much as a small thimbleful of water, and the *kilogram* is a little more than two pounds.

The beauty of the metric system is that it is based upon the number 10, so that any changes from one expression to another of lower or higher denomination may be made by simply moving the decimal point. This is so much easier and better than the awkward system in common use, that it is adopted by nearly all students of the sciences and professions which involve measurements. Unfortunately we are, as a country, slow to adopt it for common use; a fact we have all had occasion to regret.

QUESTIONS

1. What is meant by the dimensions of a body?
2. Define volume; mass; capacity.
3. How are mass and weight related?
4. What two measurements of a body are included in an expression of its density?
5. What is meant by a unit of measurement?
6. What is a standard unit? How are standard units fixed?
7. What system of measures is the standard for this country? Which is commonly used by the people?
8. In the metric system, what is the standard unit for linear measure? How are surface areas expressed? How express measures of volume?
9. What is the unit of capacity? What common measure is nearly the same in size?
10. Name the unit of mass. How is it found?
11. What is the advantage of the metric system?

SECTION VI

ENERGY AND FORCE

23. Energy. — Of greatest importance in the study of Physics is the subject of *energy*. As in the case of "matter," it is difficult to give a real definition of energy, but for convenience we may say this:

Energy is the ability to cause motion. It is not necessary that a body be actually causing motion or moving, in order that it may possess energy. An energetic fellow may for the moment be idle; he still has the *ability* and power to move and produce motion when he wants to, and so he has energy, even though he may not at the time be using it. There is energy in a coiled spring, because it may unwind and so cause motion. There is energy in coal, because by burning it we get heat, and the heat may be made to change water into steam, and the steam may set an engine in motion.

24. Force. — When the energy in a body is used and motion is thereby caused, we say that the body exerts force. This may be defined as follows:

Force is the direct cause which tends to produce motion or a change of motion.

Note that a force may not always actually cause motion, but may simply *tend* to do so. This is an expression commonly used in Physics; in this case it means that although a force may not be great enough to succeed in moving a body, still it would be called force so long as it produced upon the body any effect which inclined to move it. For example, a man might

pull on a freight car without being able to move it. He would, nevertheless, tend to move it; for if other men did just the same thing together with him, the car would be set in motion. Their combined forces move the car; each one alone simply tends to do so.

In general, motion is said to be caused *when a body is started from a state of rest.* Change of motion may be accomplished *by changing the direction or speed of a body already moving*, and *by stopping a body which is in motion.* The first of these statements may be admitted at once, but the last, perhaps, presents a difficulty. We run into a tree — or, better, we watch some one else run into a tree — and stop very suddenly. Clearly the tree stopped him; but how, we ask, can a tree exert force? Later in our study, when we consider the laws of motion, we shall learn that if any body exerts force upon another, the second at the same time exerts an equal amount of force upon the first. In running into a tree we use force upon it, which the tree at the same time uses against us in return and so stops us.

Force may also produce a change in the *size* or *shape* of a body. But as no change in size or shape can be made without some motion, molecular at least, it may be seen that the definition still holds.

25. Force and Energy distinguished. — Motion is caused directly by the action of force. A body of matter through whose agency force acts, may be said to exert force. In order that a body may *exert force*, however, it must *possess energy*. That is, a body that exerts force does so by virtue of the energy that it

possesses. Not only is a supply of energy necessary before any body can exert force, but as the action continues the supply of energy in that mass diminishes, and it may be entirely exhausted unless renewed. Thus while motion is caused by force, it is only when a body possesses energy that it can exert force.

26. Various Forces. — There are many different forces in the world; that is, many different ways in which motion may be produced. The force of *gravitation*, for example, is a property of all matter: every body, however small or great, has the power of attracting and does attract other bodies. The *elastic force* of different substances is very common, and in many ways it is used by man to help him do work. The *expansive force* of steam and other gases is another important cause of motion.

Some *molecular forces* are already known to us, such as cohesion, adhesion, etc., and others remain for later study. *Muscular force* enables man to move his own and other bodies; and we cannot fail to think of *magnetic force*, which has come to be so widely used.

Force is not a thing which we can see, and in many cases we have little idea as to why or how there is any such force. We can see only the results which the force produces, and by studying these, form our ideas about its nature and how it may be controlled. Much of our work in Physics will be to study the effects of the different forces and learn something of the laws which have been discovered concerning them.

27. Measures of Force. — In a previous section we spoke of the common spring balance as a "dynamometer," or *force measure.* We are familiar with it, however, as a device for weighing bodies; but this is perfectly possible, since all things are weighed by *measuring the force* of the earth's attraction for them. Thus the same units which are used in weighing (that is, the units of mass) may be employed equally well in measuring force. This, in fact, is just what always is done; and force or pressure is expressed in grams, kilograms, pounds, or ounces, as occasion may require.

28. Stress and Strain. — Two forces acting upon a body at the same time and equally in opposite directions

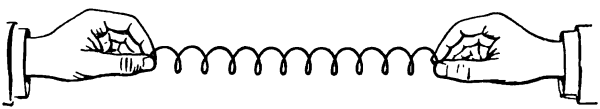

FIG. 13

may cause a change of motion in the parts of the body without causing it to move as a whole. The result would be a change in size or shape of the body. Such a pair of forces acting together would be called a *stress;* their effect on the body would be called a *strain.*

A strain is any change in the condition of a body caused by the action of two forces upon it.

A stress is a pair of forces acting to cause a strain.

The two forces may act away from or toward each other. A coiled spring drawn out (Fig. 13) would illustrate the first, and the spring pressed together (compressed) as in Fig. 14 would illustrate the second.

29. Molar and Molecular Forces. — From the definition, we must consider as a force anything which produces motion, no matter whether the body itself moves or only parts of it. *There are many motions of particles of matter so small that even a microscope fails to show them* — nothing but the *results* of the motion may be seen. Such motions are said to take place at "insensible" distances; that is, distances too small to be perceived by the senses. To illustrate: we have seen frost form as we breathe on a cold window pane, and we know that frost is only water arranged in fine crystals. The water vapor in our breath is not in the form of crystals, and clearly the particles must have arranged themselves in some way as soon as they struck the cold glass. Some *force* must have acted upon the particles; for, though we did not see it, there surely was motion among them while they were arranging themselves. Such a force is called a *molecular force*, because it acts between the molecules and is a property of the molecules.

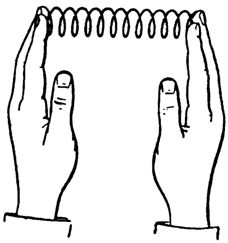

FIG. 14

This is only one example. Cohesion, which holds the parts of a body together; adhesion, which makes some particles cling to other kinds; elastic force, which resists compression or crowding of molecules; and surface tension, which makes falling drops spherical, — all these are forces which belong to and act upon molecules. Others could be cited.

For a definition we may say that *molecular forces* are those which act at insensible distances. All other forces, whose effects we may observe, are said to act at sensible distances, and are called *molar forces*.

QUESTIONS

1. What is energy? Name examples of energy which is inactive.

2. Define force. Explain how a force may tend to move a body, and yet not actually succeed.

3. In what ways may a force affect the motion of a body?

4. May a body have energy and exert no force? May it exert force without having energy?

5. Name five different sorts of forces. Name some molecular forces. Define molar forces; molecular forces.

6. What units are used in measuring force?

7. What is a stress? a strain?

8. When a body exerts force, does it lose any of its energy? Why do we feel tired or exhausted after exercising for a long time?

CHAPTER II

FLUID PRESSURE

SECTION I

THE CAUSE OF FLUID PRESSURE

30. Fluids. — Liquids and gases are called *fluids* because they flow. We are familiar enough with flowing liquids, but perhaps we have not thought of gases as flowing. Later on, however, when we know more about gases, we shall find that they, like liquids, tend to flow downward, and that a vessel full of a heavy gas may be poured out into a lighter gas just as one would pour water.

The cause of flowing, and the cause of *fluid pressure* as well, is very simple. All matter is acted upon by gravity, and every particle of every body is thus *pulled downward*, exerting pressure on anything beneath it. This is true of any sort of matter, solids as well as fluids. In solids, however, pressure is felt downwards only; for the parts of a solid do not move freely about, as they do in fluids.

In liquids and gases pressure is felt not only downward but upward and sidewise, in fact in all directions. This is because all the particles composing a fluid are free to move, and are drawn downward by the force

of gravity; when they are stopped by the bottom of the pail or dish, each particle feels the weight of many others above it, and so exerts force against its neighbors in every direction.

Artesian wells may serve to illustrate this principle. Water falling on the ground may settle into it until it strikes a layer of hard rock and can go no farther. Along this hard layer it may run until it flows beneath another hard layer nearer the surface. Should this occur in a hollow between hills, the water penned in between the two rock layers would feel pressure from that running into it from the higher slopes. If now a well be bored through the upper layer of rock, a stream of water may spurt forcibly up from the opening. This shows that the pressure in the liquid, though caused by gravity in the first place, may be exerted in other directions.

31. Pressure dependent on Depth. — If we make a hole in the bottom of a can, *A* (Fig. 15), and then push the can down into a vessel of water, we shall observe these things: first, we have to exert force to push it down; second, the farther we push it the more force we must use; third, as the can goes down water rises through the hole; fourth, the farther down the can is, the higher the stream rises.

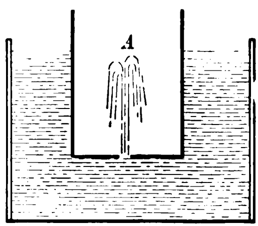

FIG. 15

The fact that it takes some force to push the can down (and also the water spouting up through the hole)

proves what was stated before, — that in a liquid pressure is upward as well as downward. The facts that it takes more force to push it as the can goes farther down, and that the water spouts with more force, show an important principle:

In liquids pressure increases as the depth increases.

The *water supply* of most cities comes from a pond or large tank (called a *reservoir*) high up on a hill. The farther up it is above the city, the greater will be the force or *head* of the water as it runs from the pipes. In this case we have to measure the "depth" of water

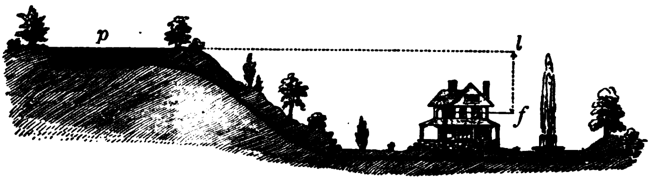

FIG. 16

as the distance from the level of the pond to the faucet from which the water runs. As in Fig. 16, the force with which water would run from a faucet at *f* would be the same as the pressure of water whose depth was the distance *f* to *l*, *l* being the level of the water in the pond *p*. A faucet higher up in the house would not get such a force of water, because the depth would be less.

The height to which a stream may reach if hose be attached directly to a "hydrant" depends upon the vertical distance from the hydrant to the surface of the reservoir. Also the distance from the tank decreases

the pressure, for the water flowing through pipes loses some of its force by rubbing on the sides of the pipe.

32. Pressure Independent of Direction. — We have learned, perhaps, that fluid pressure is exerted in all directions, and have also just seen that pressure increases with the depth. Another important principle combines the two as follows:

At the same depth pressure is equal in all directions.

To prove that pressure upward or downward at the same depth is equal, may be easy. Hold a piece of thin cardboard, *c*, to the end of a chimney, *l*, and force it down into a vessel of water, *w*, as in Fig. 17. Pour water into the chimney till it reaches the same level as the water in the vessel. Add a drop or two more, and the card will float away.

FIG. 17

When the card is first forced into the water, the liquid presses on it from beneath. As water is poured into the chimney it presses on the card from above, but not so much at first as does that below. When the water in the chimney is even with that in the vessel, the card feels equal pressure above and below, and a little

more added from above will push it down and away from the chimney. This shows us that pressure upward and downward, at the same depth, is equal. It can be proved also that the same is true of pressure in *all* directions.

Fig. 18 shows a glass vessel filled with water, in which are three tubes, *a*, *b*, and *c*. These tubes are of equal bore and contain an equal quantity of mercury; they are long enough to reach above the water, so there is atmospheric pressure upon one surface of the mercury and liquid pressure on the other in each tube. The lower ends are all different, being so arranged that the water will press upon *a* directly downward, upon *b* directly upward, and upon *c* from the side; but in all the tubes these openings are at the same depth exactly. Now although the water may actually touch the mercury in the same direction in each case, still the water in each tube simply *transmits* the pressure felt at the opening; so the height of the mercury column will be a true report of the pressure at those openings. If, now, the vessel be filled with water, the mercury column will be forced to the same height in all the tubes. This shows that at the same depth pressure is equal in these three directions, and similarly it might be proved for any or all directions.

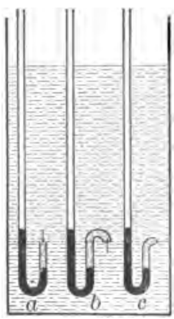

FIG. 18

33. Transmission of Liquid Pressure. — We have learned that pressure in liquids depends upon the depth. We also understand that because of the easy movement

of its molecules this pressure is *transmitted* to all parts of the liquid equally at the same depth. With this in mind it may not be hard to understand that it makes no difference what the shape or size of the vessel may be, but *the pressure upon any surface depends only upon the area of that surface and the depth of the liquid above it.* Of course we have also to consider the *density* of the liquid; as, for example, mercury, which is over thirteen times heavier than water, would press just that much more heavily. With these facts in mind it is evident

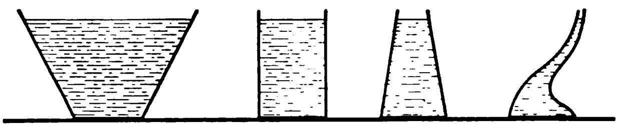

FIG. 19

that the pressure upon a surface immersed in a liquid may be measured by means of the following rule:

Find the weight of a column of the liquid having a base equal to the area pressed upon and a height equal to the average of distances from all parts of the given surface to the top of the liquid.

As has been said, the size or shape of the liquid body does not make any difference. Fig. 19 shows several vessels having each the same area of base and height of liquid. If each had a flexible bottom so the pressure could be measured, it would be found equal in all.

Fig. 20 shows a still more extreme case: *a* is a cylinder having a solid bottom which fits exactly another cylinder, *b*; *c* is a rubber tube connected so as to open into *b*. If *c* be carried to a height of about eight feet

and filled with water, as in the figure, the pressure upon *a* would equal the weight of a column of water having a base equal to the bottom area of *a* and as high as the straight-line distance from the bottom of *a* to the top of *c*. This pressure would support quite a weight upon the platform *e*, — a child, for example.

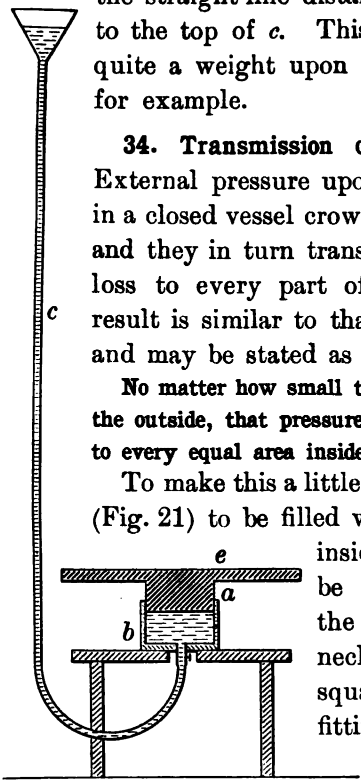

Fig. 20

34. Transmission of External Pressure. — External pressure upon the surface of a liquid in a closed vessel crowds the molecules together, and they in turn transmit the pressure without loss to every part of the whole body. The result is similar to that which we just studied, and may be stated as follows:

No matter how small the surface pressed upon from the outside, that pressure is transmitted without loss to every equal area inside.

To make this a little clearer: Suppose a bottle (Fig. 21) to be filled with water. Suppose the inside area of the bottle to be fifty square inches, and the surface of water in the neck to have an area of one square inch. If a perfectly fitting stopper be forced down upon this smaller surface with a pressure of half a pound, that half-pound pressure will be felt upon *every square inch* of surface inside the bottle; in other words, the total pressure on the bottle from inside will be ($\frac{1}{2} \times 50$) twenty-five pounds.

35. Hydraulic Press. — This principle is used to very great advantage in raising heavy bodies and doing other work where great power is needed and speed is not so important. Fig. 22 may serve to show how it is used to *compress* large volumes of hay, rags, cotton, and other things so that they may be more easily handled.

FIG. 21

At the right of the figure is a force pump, which forces water from the reservoir *r* to the press at the left. The solid cylinder *c* moves up and down in the frame of the press, carrying the platform *t* with it. The body to be pressed is crowded between the top of the frame and this platform. At each stroke of the piston *p* downward, water is forced through a pipe and

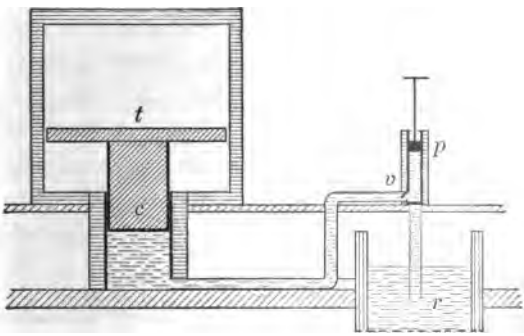

FIG. 22

pressure is felt upon the bottom of the cylinder. According to the law we have just learned, any pressure upon the water caused by the piston *will be transmitted without loss to every equal area* which the water touches, and

this of course includes the bottom of the cylinder. In other words, if the bottom of *p* is one square inch in area, every square inch on the bottom of *c* would feel a pressure equal to that used in forcing *p* downward; and if the area of *c* were one hundred square inches, for example, the pressure upon it would be one hundred times that used on *p*.

Of course on the upstroke the pressure is held by the valve *v*, so that every downstroke adds to the pressure already upon *c*. It may take a long time, but in the end a great pressure may be brought to bear upon the body in the frame.

The hydraulic jack makes use of the same principle, and is employed in lifting heavy weights.

36. Surface Level.—You probably know already that *when a liquid is not in motion its surface is level;* also that liquids tend to flow to their lowest possible level. This is due to the force of gravity. All the particles of a liquid move freely upon each other, and so when they are pulled downward by gravity they all move until hindered by some outside body.

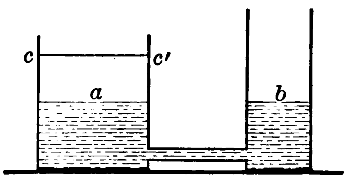

FIG. 23

If a vessel, *a* (Fig. 23), contains water to the height *cc'*, and *a* be connected with *b* by a tube at the bottom, water will flow from *a* to *b* till the level in both vessels is the same. This principle is not affected by the shape or size of the vessels.

37. Capillary Phenomena. — Capillary phenomena — so called because they are observed in tubes having a capillary (hairlike) bore — may seem at first thought to be an exception to the general law of gravitation. We shall learn, however, that they are due simply to some of the properties of matter already studied.

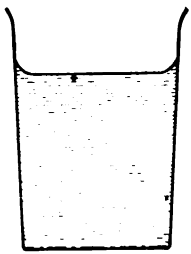

FIG. 24

Looking at the surface of water in a glass vessel (Fig. 24), we notice that instead of being entirely level the *water rises up on the glass at the edges*, meeting it at a sharp angle. Using a glass like that in Fig. 25 (a small tube attached to one very much smaller), we may notice two things: the surface in the larger tube seems curved at all points, and *the water in the smaller tube rises higher* than in the larger. Again, if we put the tube of a broken thermometer (open at both ends) into a glass of water, the level of water in the tube will be higher than in the glass. These are some of the *capillary phenomena*, and at a glance they seem to oppose what we have just learned about liquid level.

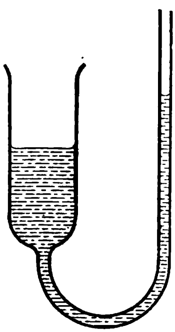

FIG. 25

Let us look for the cause. We know that drops of water cling to the bottom of a dish because the *adhesive force* between water and glass is strong enough to hold the drops up against gravity; in other words, water tends to adhere to glass, and the strength of this adhesion is greater than the force of gravity — for small

amounts of water. Therefore, if a small tube of glass be dipped into water, this adhesive force will lift a small quantity of the water up the tube higher than its level in the dish outside.

Since there is a limit to the weight of liquid which can be lifted in this way, it may be easily seen that *the smaller the bore of tubing the higher a liquid will rise in it.* Fig. 26 shows a series of tubes of different bore; notice the surface level in each as compared with the size of tube.

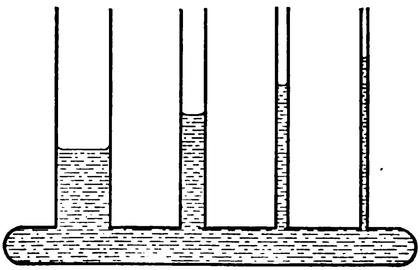

FIG. 26

It is due to this adhesive force of liquids for various capillary or *fibrous* material that oil rises through the wick in a lamp, that ink is absorbed by blotting paper, that sponges take in water, etc.

Many thin membranes will allow certain substances to diffuse through them by a process called *osmose.* In general this applies to substances that will crystallize, such as solutions of mineral salts and acids; such amorphous substances as gums, gelatin, or albumen will not thus diffuse through membranes.

QUESTIONS

1. In what direction is pressure of solid bodies felt?

2. How does fluid pressure differ from that of a solid? Why do liquids and gases flow?

3. Upon what does liquid pressure depend? What force causes fluid pressure?

4. Could a deep-sea fish live long in shallow water? Why?

5. How are cities supplied with water? How high would water rise in the pipes of a city system? Explain.

6. At the same depth what is true of liquid pressure?

7. How find the pressure on a surface in a liquid?

8. How is external pressure transmitted in a closed vessel of liquid? Would this be true of a gas?

9. What is an hydraulic press? Explain its action.

10. What advantage is gained by such a press? Name uses.

11. What is the tendency of a flowing liquid?

12. When may a surface be called level? Would the surface of a gas be level? Why?

13. What force causes surface level?

14. What molecular force causes capillary phenomena?

15. Upon what does the height of water in a capillary tube depend?

16. Why does water in a tumbler seem to have a curved surface?

17. Toward glass the behavior of mercury is opposite to that of water; where would be the surface of mercury in a capillary tube — above or below the surface outside?

SECTION II

BUOYANCY

38. Buoyant Force in Liquids. — All bodies seem to weigh less when they are held in a liquid, and some bodies which are light seem to lose all their weight and float. It must be noticed that these bodies do not actually *lose* weight in the liquid, but they *seem* to be lighter. This is because they are held up by a force acting on them from below, which partly or wholly balances the force pulling them down.

If we push a block of wood, *abcd* (Fig. 27), to the bottom of a vessel of water and then let go, the wood will rise to the surface as if pushed up from below. Let us see what it is that pushes the wood up.

We have learned that in liquids pressure increases with the depth (§ 31). Now the sides *ac* and *bd*, being at equal depths, will be pressed upon equally. But the side *cd* is farther down than the side *ab*, so the pressure upon *cd* will be greater. Thus the force acting upward is greater than that acting downward, and the body will be held up by a force equal to the difference between these two forces. This is called the *buoyant force* of the liquid.

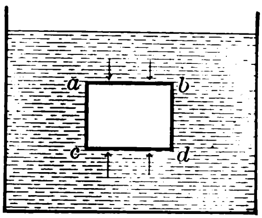

FIG. 27

We have noticed this buoyant force many times, perhaps without knowing it. In raising a bucket from a well, or a stone from the water, we know how much heavier it seems the moment it leaves the water. We can lift a stone under water which would be too heavy for us if it were on the land. In these cases we are aided by the buoyant force of the water, which ceases to help as soon as the object is out in the air.

39. Measure of Buoyancy. — This buoyant force may be easily measured, for it is the seeming *loss of weight* of any body held in a liquid.

Fill a vessel, *a* (Fig. 28), with water to the level of the spout *s*. Weigh a solid body, *r*, in the air and remember its weight. Then weigh it again, holding it

under water in the vessel *a*. The difference between these two weights gives its loss of weight in water, and hence the buoyant force of the liquid.

Now as *r* is lowered into *a*, some of the water is displaced and may be caught in a vessel, *b*. If we weigh the water which has gone into *b*, we shall find its weight

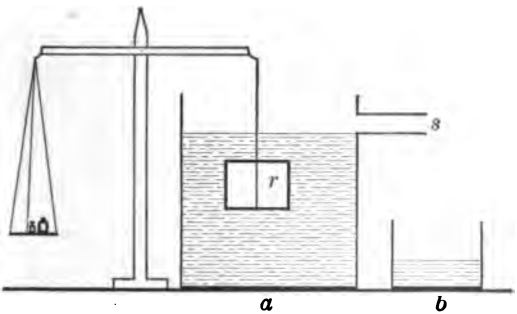

FIG. 28

just equal to the buoyant force which acted on *r*. This fact is known as the *Principle of Archimedes:*

A body held in a liquid is buoyed up with a force equal to the weight of the liquid displaced.

40. Floating Bodies. — *Whenever the buoyant force acting on a body is greater than the weight of the body*, it is held up at the surface and *floats;* in other words, any substance floats when it is lighter than an equal volume (bulk) of the liquid in which it is immersed.

We have doubtless noticed that some floating bodies sink farther into the liquid than others. Fig. 29 shows a piece of cork floating nearly all out of water; Fig. 30, a bit of wood a little more than half under; and Fig. 31,

a piece of ice which floats with only a small part of its mass above the surface.

Now since these bodies stay where they are and do not move up or down, the forces acting upon them must be equal in both directions; that is, the buoyant force holding them up is exactly equal to the force of gravity, as expressed by their weight. And as we

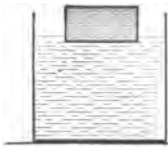

FIG. 29

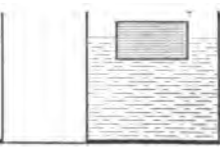

FIG. 30

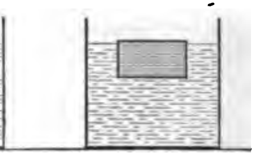

FIG. 31

have learned that the buoyant force is always equal to the weight of water displaced, we can at once form the *Law of Floating Bodies:*

All floating bodies sink into the liquid until they have displaced their own weight of it.

41. Examples of Buoyancy. — Applications of the buoyant force of liquids are common, and some of them important; but it must not be forgotten that, although we speak of it as another "force," buoyancy is in reality caused by the force of gravity. If water, for example, had no weight, — if its particles were not every one pulled downward by gravity, — there would be no difference in pressure on the different parts of a body held in it. It is because the particles of water are drawn downward with greater force than wood, for example, that the wood rises to the top, making way for them.

That *gases have this same buoyant force* is shown by any *gas balloon.* Such balloons are filled with hydrogen

or common illuminating gas, both of which are lighter than air. Therefore the buoyant force of the air (equal to the weight of air displaced by the balloon) will be great enough to force up not only the gas bag but a considerable weight besides, if the balloon be large enough. Air ships usually have a big gas bag to lift them, and are steered by means of large, fanlike propellers.

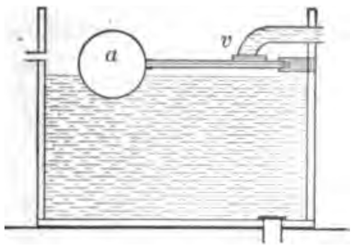

FIG. 32

Fig. 32 shows a common use of buoyancy, where it is made to keep the supply of water in a tank up to a certain level. A hollow ball, *a*, floats on the surface of the water; as the surface is lowered, *a* drops with it, opening a valve, *v*, through which more water runs from the supply pipe. When the water thus let in raises the surface to its former position once more, the ball being carried with it again closes the valve and shuts off the supply.

We may perhaps wonder why a steel war ship will float, when steel is so much heavier than water. It is because the body *as a whole* floats; and considering the vessel as a whole there is of course a great deal of space inside which contains nothing heavier than air.

42. Specific Gravity. — Weight has been found to be the measure of the force of gravity upon a body. Of course we know that the weight of anything depends very much upon the *kind of matter* of which it is made.

We have also a rough idea, perhaps, as to what sort of matter is heavy and what is light. A piece of iron, no matter what its shape or size, would always be heavier than the same volume of wood; lead or silver would be heavier than the same volume of iron; while gold and platinum are much heavier than almost any other substances.

Now, in order to express the *relative weights* of all different substances, men have first chosen some *standard* to which all may be compared. For solids and liquids the standard is *water at* 4° *Centigrade* (about 39° Fahrenheit). Any substance, then, may be weighed, and this weight compared with that of an *equal volume* of water. If an equal volume of the substance is, for example, four times as heavy as the water, we should say its *specific gravity* is four; if five and one half times, its specific gravity is 5.5, etc. Thus we may say that the specific gravity of a solid or a liquid is *the ratio of weight of a unit mass referred to a unit mass of water as a standard.* For gases, air at 0° Centigrade is commonly used as a standard.

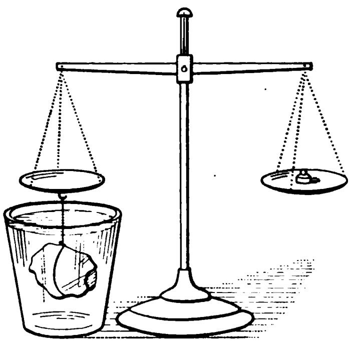

Fig. 33

43. Methods for finding Specific Gravity. — To find the specific gravity of a *solid* body, first weigh it in air, then weigh it immersed in water, as in Fig. 33.

The difference between these two will be the buoyant force of the water, which of course equals the weight of water displaced. Now we have given the *weight of the body* and the *weight of an equal volume of water;* it remains only to divide the former by the latter, and the quotient is the specific gravity which we sought. Other methods may be used, but this may serve to give a general idea.

FIG. 34

Fig. 34 shows an easy method for testing the specific gravity of *liquids*. A long glass tube, *a*, called an *hydrometer*, is weighted at the end *c*; on the stem is a graduated scale. When placed in a liquid the hydrometer will sink more or less, according as the substance is light or heavy; and the specific gravity may be read directly from the marked scale, at the point where the surface of the liquid meets it.

Following is a list of specific gravities of common solids and liquids. The standard being distilled water at 4°C., its specific gravity would of course be 1. The others are given approximately.

TABLE OF SPECIFIC GRAVITIES

Alcohol	0.8	Glass	3.4	Pine	0.6
Aluminium	2.7	Gold	19.4	Platinum	21.2
Brass	8.4	Ice	0.9	Quartz	2.7
Coal	1.8	Iron	7.2	Sea water	1.03
Copper	8.8	Lead	11.4	Silver	10.5
Cork	0.2	Mercury	13.6	Tin	7.3
Ebony	1.2	Oak	0.8	Zinc	7.1

QUESTIONS

1. What is meant by buoyant force? Explain its cause.
2. Does buoyant force act upon every body held in a liquid?
3. How measure the buoyant force acting on a body?
4. How much water is displaced by a body which sinks into it? How much by a floating body?
5. In every case (floating bodies or those which sink entirely), how does the buoyant force compare with the weight of water displaced? Why do not steel and iron vessels sink?
6. State the Law of Floating Bodies. Is this true of gases?
7. What force is the cause of buoyancy?
8. Do gases exert buoyant force? How may this be shown?
9. What is the difference between gravity and specific gravity?
10. What is the standard of sp. gr. for solids and liquids? for gases? What is meant by saying the sp. gr. of mercury is 13.6?
11. How find the sp. gr. of solids? of liquids?
12. What is the sp. gr. of water?
13. How find the sp. gr. of a body which is lighter than water?

SECTION III

ATMOSPHERIC PRESSURE

44. Meaning of Atmospheric Pressure. — The word *atmosphere* is used to denote the air about the earth. It is well to note that the expression "atmospheric pressure" has a more definite meaning than "air pressure." The latter may be used wherever air exerts pressure, — as in the case of compressed air, for example.

The atmosphere is a mixture of two or three gases. It completely surrounds the earth and extends high above us. Just how high the atmosphere does reach is not known, because it is not possible for men to go

more than five or six miles above the earth; but we have good reason to think it extends to one hundred miles above us. By far the greater part of the air is nearer the earth, however. Probably two thirds of it is within six miles of the earth; therefore it must be much thinner (or more *rare*) as we go up. One can notice the difference in density very quickly as he climbs a mountain; and one could hardly live on a peak five miles high, but would die for want of sufficient air to breathe.

45. Cause of Atmospheric Pressure. — Now how does the atmosphere exert pressure? In just the same way that liquids do, — because *gravity acts on all its particles, pulling them down.* We are not in the habit of thinking air weighs anything; yet if we stop and reflect that air is matter, and all matter is attracted by gravity, it is evident that air must have weight. This may be easily proved. Fig. 35 shows a pair of very sensitive scales. The globe *b*, full of air, is exactly balanced by the weight *a*.

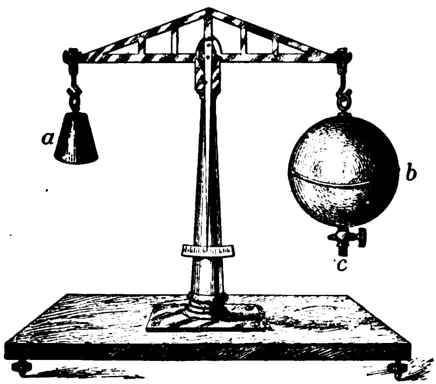

FIG. 35

If now we pump the air out of *b*, closing the cock *c* so none can get back in, the weight *a* will settle down, showing that *b* is now lighter than *a*. This proves

that a globe full of air is heavier than when it is empty: in other words, *air weighs something.*

If now we stop to consider that this air extends many miles above us, we may not be surprised to learn that *atmospheric pressure is fifteen pounds to the square inch.* This means simply that every surface exposed to the air bears a pressure of fifteen pounds on every square inch of its area. In other words, a column of air one square inch in its cross-sectional area and as high as the greatest height of air above us, would *weigh* about fifteen pounds.

The first question may be, Why are we not crushed by this weight? Simply because it presses on all sides of us, — above, below, sidewise, and inside of us even: wherever the air touches us this pressure is felt. The pressure above is balanced by that beneath, on one side by that on the other, and so on; so that, being entirely surrounded by the pressure, we do not feel it on any side.

46. The Vacuum. — Strictly speaking, a vacuum is a space in which there is no matter whatever. The word is frequently used, however, to denote *a space from which the air has been almost entirely removed.* As it is practically impossible to remove every last bit of air from a space, nearly all so-called "vacua" are only *partial vacua.* In speaking of such spaces, the word *vacuum* is of course used, the space being sufficiently devoid of matter to serve the purpose.

47. Examples of Vacua. — A simple experiment may illustrate the subject. Placing a small bottle at the lips, remove some of the air, quickly putting the tongue over

its mouth; the bottle will stick to the tongue. Some of the air being removed from the bottle, pressure is greater on the outside and it tends to push the tongue farther in. This closes the opening so that no more air can be let in, and atmospheric pressure on the outside of the bottle holds it where it is.

Breathing is accomplished by means of this principle. The lungs lie in the chest in such a way that no air can reach them except what comes through the breathing passages to their inside surface. By muscular effort the size of the chest cavity is increased. This would leave a vacuum between the lungs and walls of the chest; but air is forced by atmospheric pressure through the nose and other passages to the lungs, causing them to expand and fill the cavity.

Of course there is no pressure on the *inside* of a vacuum and fifteen pounds to every square inch on the *outside*. This great difference of pressure causes softer bodies to be crushed; and in every case *the air tends to get into a vacuum or press something else into it.*

It is important to know what a vacuum is, in order to understand some of the effects of atmospheric pressure.

FIG. 36

48. Some Examples of Atmospheric Pressure. — Fill a glass with water, cover it with a piece of paper, and hold it bottom upward (Fig. 36); the water will not run out.

This is because there is no pressure upon the liquid from above, and atmospheric pressure on the paper from beneath holds it in. (The paper simply gives the air a solid surface to press upon; if it were not there, the water could run out at one side while the air entered the tumbler at another.)

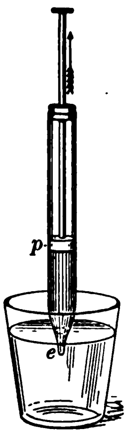

FIG. 37

If we put the end *e* of a syringe in a cup of water (Fig. 37) and draw the piston *p* upward, the tube will be filled with the liquid. As *p* is drawn upward a ***partial vacuum*** is formed in the tube (because the small amount of air is made to fill a larger space); atmospheric pressure on the water in the cup then forces it into the tube to fill the vacuum.

Fig. 38 shows a U-shaped tube partly full of mercury. In *B* the mercury stands at the same level in both arms of the tube. Tip the tube till one arm is full and close that end with the thumb. If now the tube be tipped back to its first position again, the mercury will stay as in *A*. This is because atmospheric pressure is cut off on one side by the thumb, and is felt on the mercury in the open end only. These illustrations show a few of the effects of atmospheric pressure. A moment's thought will bring to mind many others.

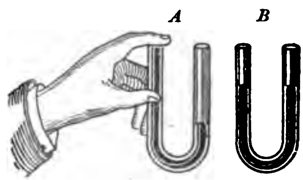

FIG. 38

49. The Barometer. — The barometer is an instrument for measuring atmospheric pressure.

Given a tube (Fig. 39) about 33 inches long, *closed at one end*, we need only a cup and some mercury to make a good barometer. Fill the tube with mercury, and put some more in the cup. Close the open end of the tube tightly, as in *A*, and invert it into the cup, being careful to keep the end closed till it is under the surface of the mercury. Opening the end of the tube now, a little mercury will run out into the cup, but enough will be left to stand about thirty inches high in the tube.

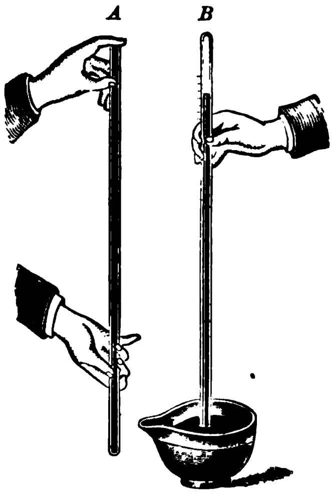

FIG. 39

The upper end of the tube is closed, and no air can get to it because the lower end is below the surface of mercury in the cup. Thus there is a vacuum above the column of mercury and atmospheric pressure at its base; in this way the column is held up.

50. Atmospheric Pressure measured. — If a uniform tube is used, whose cross section is one square inch in area, the weight of the mercury column expresses the measure of atmospheric pressure upon one square inch.

Fig. 40 may help make this clearer. The portion of mercury between *c* and *b* serves exactly the same purpose as a pair of scales. The substance to be weighed

is the column of air from *c* to the highest limit of the atmosphere, and the "weights" are represented by the column of mercury from *b* to *a*. *The mercury column just balances the column of air;* therefore, to know the weight of the air column we have only to weigh that amount of mercury between *b* and *a*. But as the air grows lighter or heavier the varying pressure on *c* causes *a* to fall or rise, in view of which fact men usually express changes in pressure by the *height* of the column *ba*, without stopping to weigh it every time.

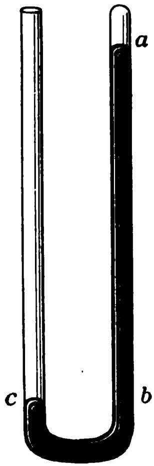

FIG. 40

This pressure varies according as the air is dry or full of moisture, warm or cold, etc. If the air is light the column may be at times as low as 29.5 inches, and when the air is heavy the column rises higher. For an average it stands at about 30 inches. In going up a mountain the air grows much rarer and the barometer column falls. The mercury has been measured at a height of nearly 28,000 feet in the air, and here it stood at 10 inches.

There are other sorts of barometers, many of them very poor. We get some idea of *weather changes* by using a barometer, for many of these changes depend upon conditions which also make the air heavy or light. The rapid falling of a barometer column means that the air is very light. Naturally the heavier air around this area crowds down upon the lighter air, forcing it upward. This creates a general movement of the atmosphere all around that place, giving rise to winds and rain.

When the upward rush of air is very rapid and confined to a small area, the winds sometimes blow in a spiral around this center of up-going air. This gives rise to tornadoes, or, as they are popularly called, "cyclones." In the center the rush of air is strong enough to carry heavy bodies far upward. Sometimes water is thus caught up, and the result is a "waterspout."

QUESTIONS

1. What is the atmosphere? How high up may men go into the atmosphere? Why not higher?
2. Why cannot a balloon go very high in air?
3. Explain the cause of atmospheric pressure.
4. How great is atmospheric pressure? How much on every square foot of surface? On a mountain would it be more or less? Why is it harder to breathe at great heights?
5. Why are we not crushed by this pressure?
6. What is a vacuum? What would be the pressure in a perfect vacuum? How is air taken into the lungs?
7. Would the atmospheric pressure be the same in a house as out of doors? Why? Suppose you cork a bottle full of air; is the pressure inside equal to that outside? Why?
8. Name some effects of atmospheric pressure.
9. What is a barometer? How is it made?
10. Could you use a tube open at both ends? Why?
11. How does the height of the barometer column show the pressure of atmosphere?
12. What differences in the atmosphere cause the barometer to rise or fall?
13. What is the condition inside the tube above the mercury?
14. Would a tube 25 inches long serve as a barometer? Why?

SECTION IV

DEVICES FOR RAISING LIQUIDS

51. Lifting Pump. — The common lifting pump furnishes a familiar example of the use of atmospheric pressure.

The principle upon which it works is simple; a very common experiment may serve to make it clear. If we put a straw in a glass of water and suck at the free end of it, we form a vacuum in the straw. Immediately the pressure on the surface of the water forces it up into the straw and so into the mouth. A pump works in a similar way, except that there is a pipe instead of a straw and a piston takes the place of the mouth.

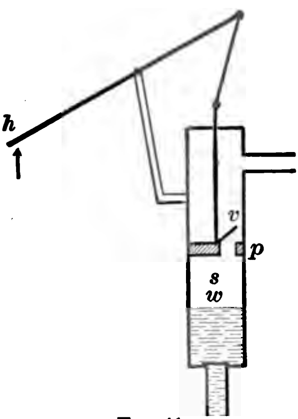

FIG. 41

In Figs. 41 and 42 *p* represents a *piston* which moves up and down in a pipe (*p* fits the pipe closely); *v* is a *valve* in the piston which closes the opening through it, *h* is the pump handle, and *w* the surface of water in the pipe. Let *x* represent the surface of water in the well.

When the pump is first started we have the conditions shown in Fig. 41. As *h* is lifted, the piston goes down; the air below *p* opens the valve *v* and escapes above it. Then when *h* is pushed down, *p* rises; the air above closes the valve and a partial

vacuum is formed in the space *s*. *Atmospheric pressure on the water in the well* (*x*) now pushes it up into the pipe to fill the space left by the air. A few strokes are enough to force the water in the pipe up to the level where the piston is moving, and then we have the conditions shown in Fig. 42.

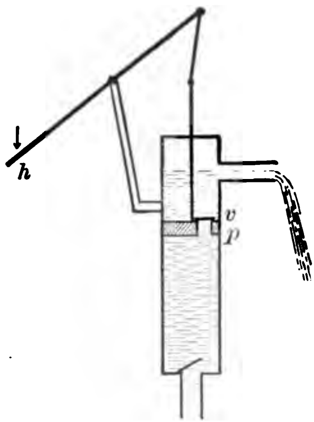

FIG. 42

In this case the piston works exactly as before, only it moves in water instead of in air. The figure shows a downward stroke of the handle *h*, the piston of course going up. The weight of water above it closes the valve *v*, the piston holds the water and raises it up to the level of the spout. At the same time *there is also a vacuum formed beneath the up-going piston*, and this at once fills again with water.

Evidently the pump is simple enough in its action. The moving piston, which closes the upper end of the pipe, is always trying to form a vacuum above the column of water; as fast as it does this the pipe is again filled by atmospheric pressure on the lower end of the column of water.

Since the water is held up by atmospheric pressure, there must be a limit to the height of the column. Usually the air will hold up a column of water thirty feet high.

The piston in common pumps is made of leather. Sometimes it shrinks and does not fit the pipe closely; then air gets above the water and it "runs down" into the well. If we put a little water into the top of the pump, it swells the leather piston and we can "catch" the water.

52. The Force Pump. — The force pump also makes use of atmospheric pressure, but for some purposes it is better than the lifting pump.

Fig. 43 is a diagram to explain the working of a common form of force pump. Instead of a piston (as in the lifting pump) there is a solid cylinder of metal, called a *plunger*, *p*, which moves up and down in the *pump barrel b*. The figure shows an upstroke. As the plunger is raised, causing a vacuum in the barrel *b*, atmospheric pressure on the water in the well forces some of it up the pipe, through the valve *a* and so into the vacuum in *b*; at the same time water in the pipe *e* shuts the valve *c*. When *p* starts on its downstroke, causing *greater pressure in the barrel b*, the valve *a* is closed, *c* is pushed open, and the water rushes out into the pipe *e*.

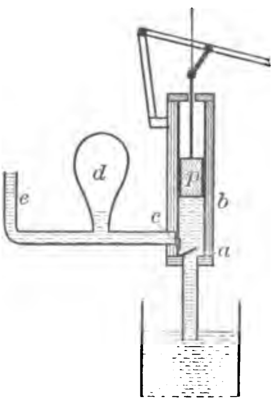

FIG. 43

The *dome d* is a feature of most force pumps. Its use is to produce a steady stream, unlike the spurting flow from a lifting pump. The dome is filled with air;

on each downstroke, water being forced into *e* partly fills the dome, *compressing the air above it.* On the upstroke of *p* the stream is kept going by pressure of the air in *d*, which *expands* and drives out the water.

The use of a lifting pump is limited to simply *raising* water short distances, because atmospheric pressure will lift the column only about thirty feet; but the height to which we can *force* water is limited only by our strength and that of the force pump. Atmospheric pressure raises it to the pump barrel, and then by the downstroke it is forced on. Force pumps run by windmills, steam, or hot-air engines, force the water to high towers or buildings. The big *steam pumps* of city waterworks often send a large stream several miles and up considerable hills. *Fire engines* are simply force pumps run by steam or other power.

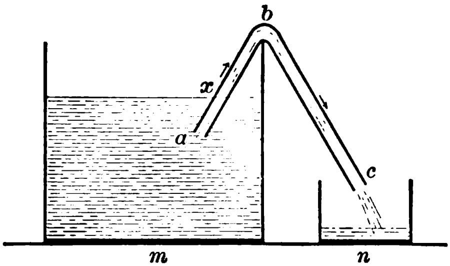

FIG. 44

53. The Siphon. — The siphon is a very simple device for removing liquids or gases quietly from one dish to another. It depends upon the *force of gravity and atmospheric pressure.*

In Fig. 44 the bent tube *abc* shows one example of a siphon. The vessel *m* contains water which is perhaps muddy at the bottom; suppose one wishes to get some

of the clear water into the vessel *n*. The siphon ***abc*** is filled with water, one end is placed in *m* and the other allowed to hang over *n*. In this position gravity acts upon the water in both arms of the tube, *ab* and *bc*. But the part *ax*, of *ab*, is under water in *m*, so the part *bx* is all that tends to run downward out of the tube. The arm *bc*, however, is much longer and heavier than *bx*; therefore *gravity will act more strongly upon bc*, and the water will run down and out at *c*. This leaves a vacuum in the tube at *b*, and *atmospheric pressure immediately forces water up ab*, keeping the tube full. Thus the water keeps running from *m* to *n* till the end *a* is out of water, or the surface in *m* falls below the level of *c*.

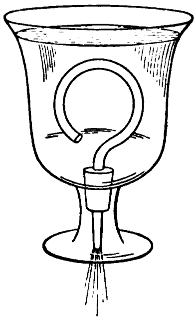

FIG. 45

Siphons may be of many different shapes and kinds, but the principle is the same in any case. They are very convenient for removing liquids from any vessel out of which they could not be poured easily.

A piece of flexible rubber tubing makes a good siphon. Put the tubing, open at both ends, wholly into the liquid; tightly pinch one end so as to exclude all air, lift that end out and over the edge of the vessel, taking care that the other end does not for an instant come out of the liquid. Lower the closed end till it is below the surface level of the liquid and then let go. The flow may be stopped by pinching the tube together.

Fig. 45 shows a siphon known as a *Tantalus cup*. When will the water stop flowing?

QUESTIONS

1. What force helps us raise liquids by means of a pump? How high can water be raised by this force?
2. Explain the action of the lifting pump. Is the water raised on a downstroke or upstroke of the piston?
3. Why does a pump "run down"? How may it be "caught"? Why do we sometimes pump a few strokes before water comes?
4. Explain the action of the force pump. What advantage has the force pump over the lifting pump?
5. What is the use of the dome?
6. Which pump is run by steam, wind, and other power at times? Which sort would be used in fire engines?
7. What is a siphon? Explain its action; its uses.
8. What forces are used by the siphon?
9. When will a stream cease to run from the siphon?

SECTION V

SOME PROPERTIES OF GASES

54. Expansion. — Gases have been defined as those bodies of matter which cannot be confined except in a closed vessel. If any opening were left, little by little the gas would escape, and its place would be filled by air or whatever gas or liquid surrounded the vessel. This is called *diffusion*, and is due to the same cause as is the expansion of gaseous bodies.

The *expansion* of gases means simply that they tend always to occupy a larger space, and if free to do so they will *increase their volume indefinitely*. This feature belongs to gases alone. It is explained, according to the molecular theory, by the rapid motion of the gaseous molecules and the absence of any cohesive force to keep them from separating indefinitely (§ 7).

The *normal* volume of a gas is regarded as the quantity which would fill any space, under pressure equal to that of the atmosphere. In other words, if we have a jar full of a pure gas, having filled it under ordinary atmospheric pressure, the gas is said to be in its normal condition. If some of it were removed from the jar, that which remained would be said to be *rarefied*. If to the normal volume we added some more gas, we should have to force it in, and the resulting volume of gas would be said to be *condensed* or *compressed*.

55. The Air Pump. — An air pump is a device for rarefying the volume of a gas. Its common use is to remove the air from any space with a view to obtaining, as nearly as possible, a vacuum.

Fig. 46 may help show the workings of a common air pump: *p* is a piston which moves up and down in the pump barrel, *a* is a valve opening into the barrel, and *c* is a valve in the piston. The air is to be removed from the bell glass *r*, which is called a *receiver;* it rests on a metallic plate, *e*, which is usually covered with soap or some similar substance to make the glass fit tightly. The tube *t* connects pump and receiver. In its action the air pump is so like the lifting pump that a glance shows it clearly: on a downstroke *a* closes, *c* is open, and the air gets above the piston; on the upstroke *c* closes, lifting the air up and out at *o*, while *a* opens to admit more air.

The difference between this and the lifting pump is simply that in this case the pump barrel is filled with air, not by atmospheric pressure but by the *expansive*

force of the air in the receiver. As the amount left in *r* grows less at every stroke, the expansive force grows weaker and the amount removed grows smaller. When finally the gas left in *r* is so rare that its expansive force is no longer great enough to open the valves, action ceases and no more can be removed.

From this it is evident that there must still be some air left in *r*; that is, the vacuum formed is not *perfect*

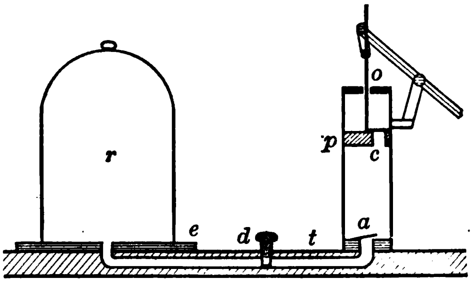

FIG. 46

but only a *partial vacuum*. With this sort of air pump it is not possible to get a perfect vacuum.

Anything from which one wishes to remove the air may be placed under the bell glass. For performing experiments, many pieces of apparatus are fitted with screw threads which fit the end of the tube as it comes through the plate *e*. A stopcock, *d*, prevents any return of air through the pump.

56. The Mercury Air Pump.—The vacuum formed by using a common air pump cannot be complete because of the force needed to work the valves. A mercury air

pump does away with this difficulty by having no valves to be opened by the gas.

Fig. 47 shows a pump of this sort in diagram. In the figure, *a* and *b* are glass globes connected by a flexible tube, *t*; the vessel to be pumped out is attached at *r*, and the air is to escape at *c*. A stopcock, *d*, to be worked by hand, is shown again more fully in Fig. 48. Notice carefully that in the position *m* (Fig. 48) the tube is open between *r* and *b*, but closed to any connection with *c*; in *n* the cock is turned so that the path from *b* to *c* is open, but *r* is now shut off.

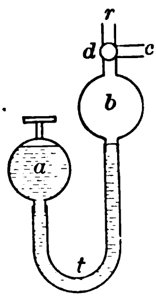

FIG. 47

To operate the pump: Fill *a* with a quantity of mercury; raise it above *b* till the mercury runs through the flexible tube *t* and fills the globe *b*. In order to do this the cock *d* must be turned as in *n*. Now turn the cock as in *m*; this shuts off *c* and opens a passage between the vessel to be emptied (at *r*) and the globe *b*. Lower the globe *a*; the mercury runs from *b* into *a* by force of gravity, and the vacuum left in *b* is filled by the expansive force of air in the vessel. Once again turning *d* to the position *n*, raise *a* as before, and the mercury running into *b* drives the air out at *c*. This may be done till air is almost perfectly removed from the vessel.

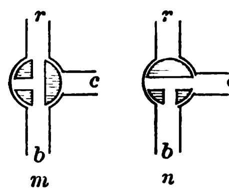

FIG. 48

As has been said, there are no valves to be moved; *the air has only to expand and go through an open tube into a vacuum.* As a result an almost perfect vacuum

may be obtained. It is possible with such a pump to rarefy the air to one millionth of its normal pressure. One of its common uses is to rarefy the air in the glass globes of incandescent electric lamps.

A vacuum such as that in the globe *b* when the mercury is lowered, would be nearly perfect if connection with *c* and *r* were closed. It is formed in the same way as that in the barometer tube above the mercury. It is the most nearly perfect which man can make (in theory it is perfect), and is called a *Torricellian vacuum* after the man who made the first barometer.

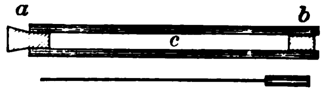

FIG. 49

57. Compression. — A gas which is under more than normal (*i.e.* atmospheric) pressure is said to be *compressed.* Its molecules are pushed nearer together. A gas may be compressed either by *decreasing the size of the space* in which it is confined or by *forcing an additional amount into a space* already containing a normal volume.

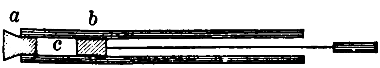

FIG. 50

The first method is used in the familiar popgun, shown in section in Fig. 49. Two stoppers, *a* and *b*, are fitted into the ends of a hollow piece of wood; by means of a stick *b* is forced through the tube towards *a*. Thus the air in the space *c* becomes compressed (Fig. 50) and exerts force upon *a* sufficient to throw it some distance.

58. The Condenser. — A device for forcing gases into a space under pressure is shown in Fig. 51. The cylinder is much the same as a pump barrel, except that the valves open in just the opposite direction from those of a pump. The vessel to be filled is attached at *b*. A downstroke is shown in the figure; compressed by force of the stroke, the gas in *e* closes *c* and opens *a*, escaping through *b* into the desired receiver. On the upstroke *a* is closed by the pressure below it, *c* is opened by the gas above, and *e* is filled. Bicycle and carriage tires, footballs, cushions, etc., which contain air under considerable pressure, are *inflated* by devices of this kind. Usually a tire contains a valve, which makes the valve *a* unnecessary.

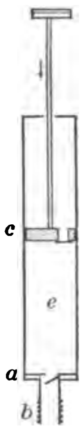

FIG. 51

59. Compressed Air. — The expansive force of compressed air is great. *Owing to its elasticity any compressed gas seeks to expand, and in so doing it exerts force equal to that used in compressing it.* For this reason compressed air is much used as a *motive force.* Pneumatic guns, mail-delivery systems, air brakes on trains, and other applications are common. Even locomotive engines are made to run by the power of compressed air. One of these locomotives is shown in Plate II. Air is forced into the large cylinder under very high pressure; from this it is allowed to flow, little by little, into a smaller cylinder, in which the pressure is constant. The engine is supplied with compressed air from this smaller cylinder, and its action is quite like that of a common steam engine.

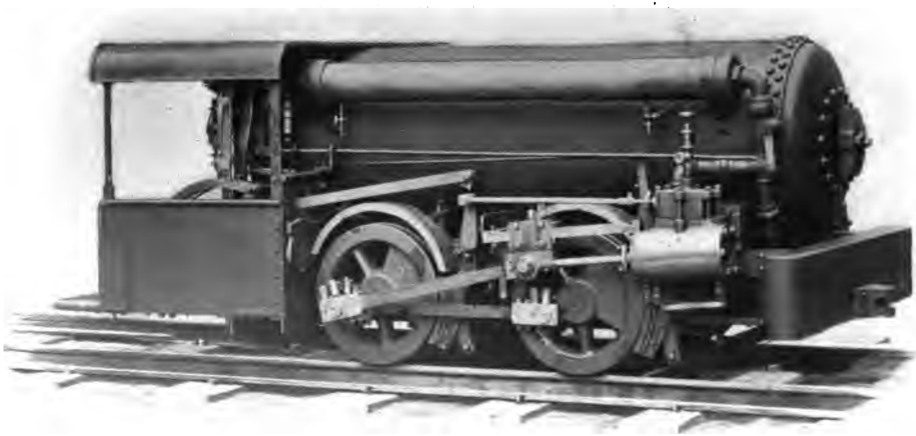

PLATE II. A COMPRESSED-AIR LOCOMOTIVE

QUESTIONS

1. What is meant by expansion of gases? How is it explained?
2. What is a normal volume of gas? a rarefied gas?
3. What is an air pump? Explain its use, drawing a diagram.
4. By what force is the air pushed out of the receiver?
5. What is a partial vacuum? Why can we not obtain a perfect vacuum with the air pump?
6. Explain the mercury air pump.
7. Why is it possible to get a more nearly perfect vacuum with the mercury air pump?
8. What is the rarest vacuum you can think of?
9. What is a compressed gas? How may a gas be compressed?
10. How does a condenser differ from an air pump?
11. To what property does a compressed gas owe its expansive force? How much force does a compressed gas exert when it expands?
12. Name uses of compressed air.

CHAPTER III

MOTION AND FORCE

SECTION I

MOTION: DEFINITIONS

60. Motion. — From the definition we learned that Physics includes a study of the *motions* of matter (§ 2). Other definitions have stated that "energy is the ability to cause motion" (§ 23) and "force is the direct cause of motion" (§ 24). A moment's thought upon these statements can hardly fail to show the importance of the subject from the standpoint of Physical Science.

Moreover, it is not necessary to make any effort whatever in order to call to mind scores of examples which show how closely connected with the study of matter is that of motion. One cause and another may produce it, and the results may differ almost infinitely; but in some way or other motion is always prominently before us, and it demands a bit of attention.

61. Motion defined. — A definition of motion may perhaps seem unnecessary, yet there is a thought involved which demands some attention:

Motion is a continuous change of position by any body. This may apply to all sorts of matter, even to the molecules.

Such change of position may be determined by considering the relation of the moving body to some other which is not moving, or is moving with a different speed or direction. In other words, a body is in motion so long as the *direction or distance* between it and some stationary body continuously changes.

A body may be in motion if considered with relation to some other body and still be at rest as regards a third. For example, riding upon a train we are in motion as regards the objects outside the car and at rest if considered with relation to the car itself.

Again, it may happen that a body moves forward with regard to one object and backward with relation to another. For example, we attempt to run after some one riding, but keep losing ground; surely we are rapidly moving forward as regards the trees and roadside, but with reference to the rider we are moving backward, because the distance between is constantly becoming greater.

62. Kinds of Motion. — When a body moves as a whole *from one place to another*, the motion is called *translation*. In such a motion the parts of the body do not change their positions with relation to each other. When translation (or a "translatory" motion) takes place along a *straight* line, the motion is said to be *rectilinear*. When the line of motion *continuously curves*, the motion is called *curvilinear*.

A body may move *upon itself* in such a way that the direction from each particle to the others constantly changes. A top does this in spinning — turning about an imaginary line in the center called its *axis*. When

a body *turns about an axis* without regard to any movement of translation, it is said to *rotate*, or to have a "rotary" motion. The motion of the earth, which makes the sun seem to pass over us each day, is a rotary movement; the axis of the earth's rotation passes through the poles.

When a body moves *about another* continuously, as *a* (in Fig. 52) about *b*, it is said to *revolve*. The earth revolves about the sun, for example; a wheel revolves about its axle.

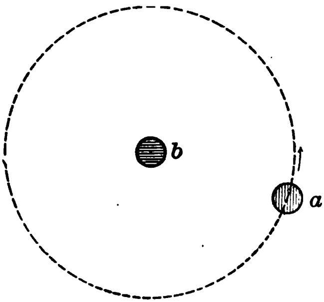

FIG. 52

The *to-and-fro* motion of a pendulum is called a "vibratory" movement, or *vibration*. This sort of motion it will be well to keep in mind for future study. Vibrations may be extremely rapid. We have seen a bell or tumbler or bit of stretched rubber make a very rapid "buzzing" movement when struck; this movement, too quick to be followed easily with the eye, is made up of very many of these little vibrations. There are many other sorts of motion, but these are the more common.

63. Molecular Motions. — The molecular forces, being of a nature similar to forces which act at greater distances, produce changes of motion among the molecules. Such *molecular motions*, while they may not themselves be seen, cause many changes in matter which may easily be seen or felt. Thus a change of

size or shape, which is made without loss or addition of matter to the body, may be the result of motion among the molecules.

If we do not consider this molecular motion, our definition of force may seem untrue; for we may think of force used in some cases where no motion seemed to result. But remembering about the molecular theory, we can easily understand that *changes in the shape or size of bodies may be the result of motion among their molecules.*

64. Velocity. — *Velocity* expresses the *rate of motion* at any instant while a body is changing its position. It considers the *distance* traveled and the *time* consumed. Such expressions as "sixty miles an hour" or "ten feet per second" are familiar, and they are expressions of velocity. To say a train is going at a velocity of sixty miles an hour does not mean that it has actually gone that distance in an hour or that it is about to do so; it means that for the moment the train is traveling with a speed which, if kept up, would in an hour's time carry it sixty miles. To say a gun has a "muzzle velocity" of one thousand feet per second means that as a bullet leaves the muzzle it is going with a speed which, if kept up for one second, would carry it in a straight line one thousand feet; but the bullet does not keep up that velocity, even for a small fraction of a second, and with every change in speed, however small, its velocity changes.

The term *speed* may sometimes be used instead of *velocity*. But it has not the same meaning exactly. Velocity is the rate of motion *in a straight line*, while

speed makes no account of direction. A body could move in a *curved* path with a certain "speed"; its "velocity" at any moment would be the rate at which it would move along a straight line, *ac* (Fig. 53), if its speed remained unchanged. The difference is a fine one, but it is always better to use the correct word; and for expressing the *rate* of change of position *velocity* is much the better.

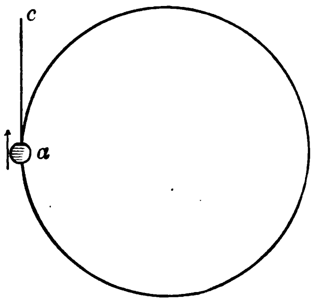

FIG. 53

The velocity of any motion may be expressed by dividing the distance traveled by the time taken.

65. Acceleration.—Motion is said to be accelerated if the moving body be made to move faster or slower, or if the direction of motion be changed. The *rate of change of velocity* is called the *acceleration.*

One who rides a wheel cannot start from a state of rest and at once reach his greatest speed. For the first few seconds he works to accelerate his motion; that is, with every push he goes faster. The brakes on a train accelerate its motion when they serve to bring it to a stop from a high degree of speed; this is called *negative acceleration.*

When the acceleration is constant,—that is, when a force is acting so as to cause equal changes of velocity in successive equal intervals of time,—it is said to be *uniform.* For example, the force of gravity is constant: in every second its action is exactly equal; therefore a

body acted upon by gravity would increase its velocity by an equal amount every second. Such motion is called *uniformly accelerated motion.*

QUESTIONS

1. What is meant by motion? How may the motion of a body be determined?
2. Give an example of two moving bodies which are at rest as regards each other.
3. What sort of motion is called "translation"? Give example. When is motion rectilinear? curvilinear?
4. What sort of motion is rotation? What is an axis?
5. What is vibratory motion? Give examples of vibration.
6. What changes in bodies result from molecular motion?
7. Define velocity. How is velocity usually expressed?
8. Explain the difference between speed and velocity.
9. What is meant by acceleration? negative acceleration?
10. What is uniformly accelerated motion?
11. Give examples of acceleration; of negative acceleration; of uniform acceleration.

SECTION II

NEWTON'S THREE LAWS OF MOTION

66. Newton's Laws. — As has been said before, a natural law is simply a statement of the behavior of matter, which men have learned by watching and studying matter itself. The *Laws of Motion* tell us of the way moving bodies act. They are called Newton's Laws, because Sir Isaac Newton was the man who studied them out and first gave them to the world. That was over two hundred years ago, and all studies of matter since his time have failed to prove them wrong. They are as follows:

FIRST LAW: **A body at rest will stay at rest, and a body in motion will keep moving in a straight line with the same velocity, unless acted upon by some outside force.**

SECOND LAW: **A change of motion takes the direction of the force which causes it, and is proportional to the amount of force used and the time during which it acts.**

THIRD LAW: **To every action there is an equal reaction in the opposite direction.**

67. The First Law: Inertia. — The first law is simple and easily explains itself if we take it to mean just what it says. It presents a new thought, perhaps, which it may at first seem hard to believe. There is no better way to test it, however, than to use a little common sense; how can any body be moved or any moving body be stopped unless force is applied to it from without? Think of any examples you please and then ask yourself, Was not some *outside force* applied to move or stop the body?

We throw a ball and it seems to stop soon all of itself; what stopped it? The force of gravity drew the ball to the earth, where it rolled till the force we gave it was used up in overcoming the resistance offered by the ground. Also as the ball goes through the air, the air resists its passage and tends to stop it. A locomotive engine or an electric car may, perhaps, seem to be bodies which can put themselves in motion; but do they? A moment's thought will show that it is the steam in the first case and electricity in the second which causes the body to move — both *outside* forces. A spring may sometimes seem to move itself; but a coiled spring in unwinding exerts only the force which was put into it when we

wound it up. And so with any example of this sort: if we know enough about it we shall find that in every case where motion is produced or stopped, some outside force caused the change.

We may wonder why it is, if this law is true, that there are no examples of a body in motion which never stops. The answer is simply that it is impossible on the earth to get any body free from the action of an outside force. All bodies are acted upon by gravity at least, and gravity pulls any moving body down till it rests upon something; then if the body does not stop at once, there will be friction enough to stop it in time. Also any moving body in the air is resisted by the air which rubs against it. The only familiar example of constant motion is given us by the stars and planets. They move, so far as man can tell, with constant speed from year to year — probably because they have been set in motion, and now there is no force either to stop them or to make them move faster.

We shall consider this important law again under the subject of Momentum. It may, perhaps, seem a little strange at first, but really it means only this, that *matter of itself has no power to change its motion in any way.*

This helplessness of matter is called *inertia.* It is sometimes spoken of as a property of matter, but it certainly is a very negative property at best.

68. The Second Law. — Like the first, this law almost explains itself (§ 66). We know that whenever force is applied to a body, the body moves in the same direction

as the force. *No matter how many other forces are acting, the effect of each force appears in the result.*

For example, suppose a force, *f*, to act upon a body at *a* (Fig. 54) so as to carry the body to *b* along the line *ab*. At the same time another force, *f'*, acts so as to carry the body from *a* to *c* along the line *ac*. Now *a* cannot get to *b* because the force *f'* pulls it down, nor can it get to *c* because *f* carries it along. The result is that the body moves to *d* along the line *ad*. A glance at the figure shows that *d* is as far to the left as *b* and as far down as *c*; thus the force *f* has moved the body as far to the left as if it had acted alone, and *f'* has moved it as far down.

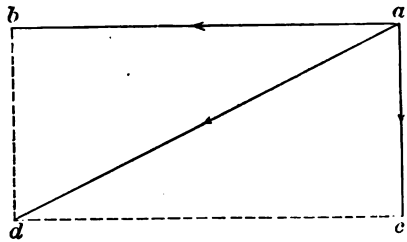

Fig. 54

To prove this, with two mallets strike a ball, *a* (Fig. 55), two equal blows at the same moment. If one is held so as to drive the ball toward *b* and the other so as to drive it toward *c*, the ball will move toward *d* along the line *ad*.

So in any case, no matter how many forces are acting on a body, no matter whether it is already in motion or not, a given force always produces the same amount of motion.

When two forces act upon a body in opposite directions, the body moves in the direction of the greater with a force equal to the difference between the two.

The last part of the second law says that the motion is proportional to the amount of force and the time.

It needs no explanation or proof to show the truth of that. It means simply that *the greater the force used or the longer the time it is applied, the more motion will be caused.* If two boys each draw a cart for five minutes, A using twice as much strength as B, of course A will go twice as far; or if both use the same amount of strength, and A pulls twice as long a time as B, then again A will go twice as far as B. This explains the meaning of the latter part of the law. End,

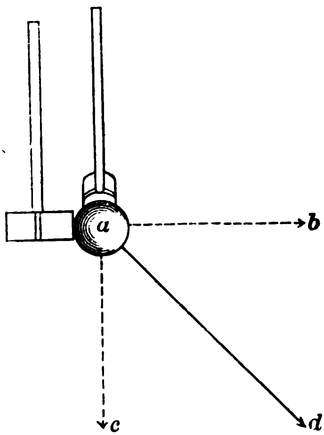

FIG. 55

69. The Third Law. — This statement (§ 66) means simply that whenever any body exerts force upon another, the second one *in resisting that force* exerts the same amount upon the first, in the opposite direction. If, for example, you strike the wall with your fist, you exert force against the wall; at the same time the wall exerts force on your fist, which is felt as pain. If you hit harder the injury is greater, because you are exerting more force upon the wall, and it in turn has to exert a greater amount on your fist to stop it.

Now we might strike a cushion or a pillow with the same force and not be hurt. This is because the motion of the hand is stopped little by little as it sinks into the cushion. On the same principle springs and cushions

make cars and carriages more comfortable. Many of the little jars and motions made when the wheels pass over rough places use up all their force *gradually* in bending the elastic springs, and are never felt by us.

The fact expressed in this third law is very useful in many ways. A common example is found in screws of all kinds. Fig. 56 shows a common screw, *A*, and a diagram, *B*, to show its action. As the screw is turned from left to right, each of the threads presses its upper face, *a*, hard against the opposite face of the wood. It is the *reaction* of these wooden faces upon the threads of the screw, which forces it onward into the wood.

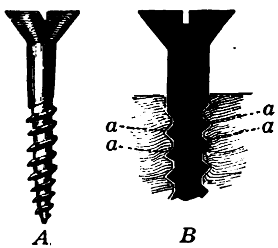

FIG. 56

Many steamships have "screw propellers." These are three-bladed (sometimes four-bladed) wheels, the blades being set at an angle like the threads of a screw. The propeller turns like a screw and presses backward on the water; as it does so, the reaction of the water upon the blades pushes them and the whole boat forward.

In batting a baseball the *reaction* of the ball upon the bat is quite as important in driving the ball as is the *action* of the club. The bat, striking the somewhat elastic ball, bends that part of the ball inward; but being elastic, the ball quickly assumes its former shape, and in so doing reacts on the bat. To prove that this helps project the ball to a greater distance, try batting a stone of the same weight with the same bat and equal strength,

and note the difference. A bird in flying beats downward with his wings, and the reaction of the air upon them lifts the bird upward. Other examples of motion caused by "reaction" will come easily to mind when we fully understand its meaning.

QUESTIONS

1. Who was Newton?
2. State Newton's three Laws of Motion.
3. Can any body at rest put itself in motion? What causes a watch spring to unwind? Why does an apple fall?
4. Can a body in motion stop itself? What force or forces act to stop a thrown ball? a rolling ball?
5. What force always acts upon bodies on earth? What other force must usually be considered?
6. What is inertia? Do all bodies have inertia?
7. According to the second law a given force always accomplishes a certain result; would the force of gravity pull two balls to earth in the same time, provided one were dropped and the other, at the same height, were thrown horizontally?
8. Why are we hurt if we strike a wall with our fists? Why does a pillow hurt less if similarly struck?
9. How do springs make carriages more comfortable?
10. Explain how reaction on a screw propeller drives a boat forward. Show why a ball may be batted farther than a stone.

SECTION III

MOMENTUM

70. Momentum defined. — The *momentum* of a body may be described as its "quantity of motion." From the first law of motion we learned that any moving body will keep on moving unless stopped by some outside force; therefore all moving bodies have momentum. Every one knows that the faster we are running the

harder it is to stop; we can "coast" a long way on a wheel after we have stopped pedaling; we have been on a car some time when it stopped suddenly, and know how one pitches forward; or perhaps we have suddenly gone over the handle bar when we were wheeling fast and struck something. In each of these cases the moving body tends to remain in the same state of motion because it has inertia (§ 67). The moving body has a certain "quantity of motion," or momentum, which must be entirely overcome by some opposing force before the body can come to rest. The greater the momentum of the body the more force will be required to stop it. This force may be applied rapidly, as when a thrown ball strikes a fence, or gradually, as friction stops a rolling coin.

71. Measure of Momentum. — Every one knows by experience that the *faster* a body is moving the harder it is to stop it; also the *heavier* a body, the more force is needed to stop it. In other words, the momentum of any moving body varies as its weight and the speed with which it is going. Or, as it is usually expressed,

The momentum of any body equals the product of its mass by its velocity.

Examples of this are very common. If we run against a tree, we are hurt more if we are moving faster; our momentum is greater and so it takes more force to stop us. The faster a train is moving, the more it breaks up things when it strikes an obstacle. A rifle ball, because it is going very fast, will go through a board before it is stopped; but fire a heavy cannon ball with the same speed and it will go through iron plate. This

is because the cannon ball weighs so much more that its momentum is far greater than the rifle bullet's, when it has the same speed.

When a player throws or bats a ball, he can exert no force upon it after it has left his hands. All he can do is to *give it a certain speed*, and then it travels *as far as its momentum will carry it.* If two boys throw the same ball the weight is the same, and so the one who gives it the greater speed throws it farther. All know that some stones are too heavy and some too light to be thrown far. As for the heavy ones, we cannot throw them with enough speed to give them much momentum; and the greatest speed we can give to the light ones does not make up for their lack of weight. Let us remember, then, that the momentum depends upon the weight and the speed of the moving body.

QUESTIONS

1. What is momentum? Give examples.
2. Upon what does the momentum of a body depend?
3. Why is it difficult to throw a wad of paper very far?
4. Why is more damage done by an express train than by a freight in striking an obstruction?
5. A rifle ball weighing one half an ounce moves at a rate of one thousand feet per second, and a cannon ball weighing forty pounds rolls at a rate of one foot per second; which has the greater momentum? By which would you prefer to be struck? Why?
6. Why does a woodcutter sometimes fasten his ax in a stick and then invert it, striking his block with the stick uppermost?

SECTION IV

CENTER OF GRAVITY

72. Explanation.—*The center of gravity* (c.g.) *of a body is the point about which its mass seems to be centered.* We have all tried at some time to "balance" something; we find, by several trials, a point where we may put a finger and support the object. That point for which we are seeking is the center of gravity of the body. *When a support is placed under its center of gravity, a body will not fall,* even if other parts of it are not supported.

FIG. 57

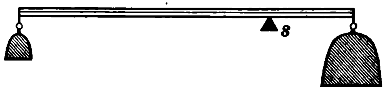

FIG. 58

Fig. 57 shows a stick of wood which is of the same size and weight all through its length; its *mass,* then, would be centered at the middle, and here a support, *s,* will hold it up. If, now, unequal weights be put on each end, the mass will be centered nearer the heavier weight, and the support *s* will have to be placed under this center to keep the body balanced (Fig. 58).

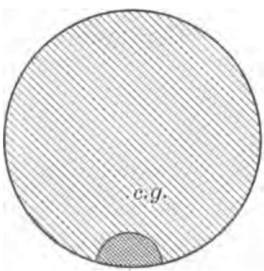

FIG. 59

Notice that the *center of gravity in a body is not, of necessity, the center of the figure.* The center of gravity of a sphere should be about the center of the figure. But if a hole be bored in a wooden ball and

filled with lead, the ball will not stay in any position except the one shown in Fig. 59; it will roll until the lead is as low as possible. This is because the c.g. is no longer in the center of the sphere, but has moved toward the greatest mass. The c.g. of the earth is not exactly in the geographical center, but is a little bit away from it. This is due to the uneven arrangement of the material composing the earth.

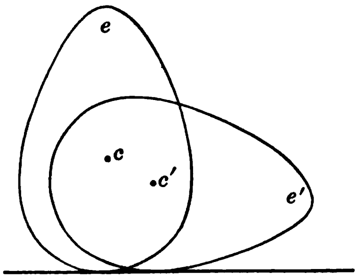

FIG. 60

73. Position of the Center of Gravity. — All bodies on or near the earth are drawn towards it. Not only that, but bodies on the earth would fall down farther if there were a hole to fall into. If this hole went straight through the earth, a body would fall to the earth's center. The momentum gained in falling would perhaps carry it beyond; but it would soon turn and fall back, passing the center again and after a few turns coming to rest (as a pendulum does) near the center of the earth. This point near the earth's center, toward which all bodies are drawn, is called the center of gravity of the earth. Therefore *when gravity acts upon any body, it tries to draw the center of gravity of the body as near as possible to the center of gravity of the earth.*

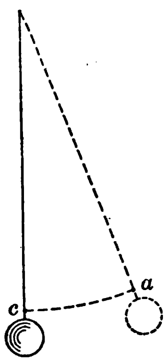

FIG. 61

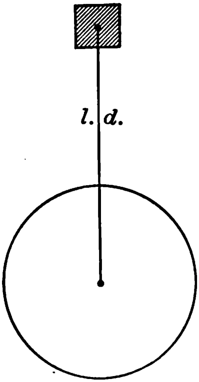

FIG. 62

This is about the same as saying that the c.g. of any body *tends to be as low as possible.* When a body is free to move, it will move until some *support* is supplied which is strong enough to overcome gravity. A falling body not only falls till it strikes a support, but if free to turn over, it does so until its c.g. is at its lowest possible position. This explains why, after jumping down from a height, we sometimes find it hard to stand on our feet: the center of gravity of our bodies, being near the actual center, tends to keep on falling till we are flat on the ground.

As a result of this principle, any body which is free to move will take up a position which will bring its c.g. as low as possible. This fact explains many common phenomena. For instance, an egg will not lie upon an end, but upon its side. Its curved surface makes it very easily moved, and (Fig. 60) its c.g. is lower when it rests upon its side. Any body suspended so as to hang freely will take a position such that its c.g. will be as low as possible (Fig. 61). Any movement sidewise would at once raise its c.g., as *ca.*

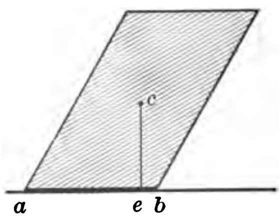

FIG. 63

74. The Line of Direction. — *When a body falls freely, its center of gravity falls in a straight line.* No matter how much the

body may turn or twist in falling, its c.g. falls straight toward the center of gravity of the earth. The line along which it falls (that is, a line joining its c.g. to the c.g. of the earth) is called the *line of direction* (Fig. 62).

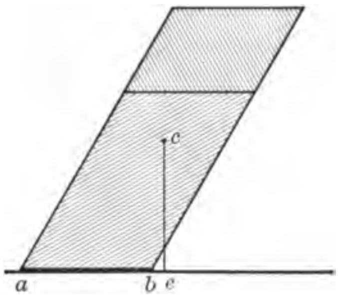

FIG. 64

75. The Problem of Support. — A little thought will show that when a support is placed so as to cut this line of direction, the body will be held up.

Fig. 63 shows a leaning block; *c* is its center of gravity, *ce* the line of direction, and *ab* the base on which it rests. A glance shows that *ce* passes *inside the base*, and the body will not fall over. If we add to the block, as in Fig. 64, *c* is higher (because it must always be the center of mass of the whole body), *ce* falls outside the base *ab*, and the block will fall over. The result of these facts may be stated as follows:

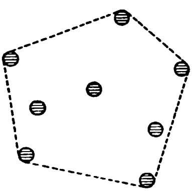
FIG. 65

A body will not fall if the line of direction passes inside its base, no matter how small the base may be; but if the line of direction passes outside the base, the body will fall.

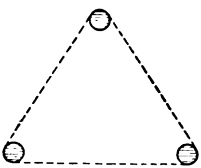
FIG. 66

The *base* of any body means the surface included by lines drawn from one to another of its *outside* points of support, taken in order. In Fig. 65

the body has eight points of support, but the base is the area included by the dotted line around the outside points. Fig. 66 shows the base of a stool to be the area included by lines drawn from one leg to the others. In Fig. 67 the dotted line shows the base of a person standing. In these cases, as in many others, it is easily seen that the line of direction may pass inside the base, even if it does not pass through a point where the body is actually touching its support.

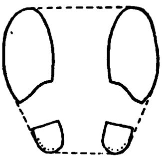

FIG. 67

76. Equilibrium. — A pencil may be balanced on the finger or upon even a smaller base, provided that the base be directly under a certain point within the pencil. When a pencil is so supported, it is clear that the force of gravity acting upon the side *ac* (Fig. 68) just equals the force acting on the side *cb*; in other words, the forces are in "equilibrium."

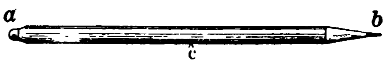

FIG. 68

An *equilibrium of forces* is a condition in which two or more forces acting upon a body exactly balance each other. It is evident that such forces will not produce motion so long as they remain in equilibrium.

If unequal forces act upon a body, the smaller force may partially balance the larger; but there will be a remainder of the larger force capable of causing motion. The total amount of any force which is not balanced by other forces is called *unbalanced force. An unbalanced force always tends to produce a change of motion.*

77. States of Equilibrium. — The action of gravity affords a good opportunity to study equilibrium; for it may be considered as several forces acting upon different parts of a body. We have seen that a body, to be supported, must have its center of gravity in line with its point of support and the c.g. of the earth. But the point of support may be *above* its center of gravity, *below* it, or *coincident* with it (*i.e.* at the same spot), and so we may discover three conditions or states of equilibrium.

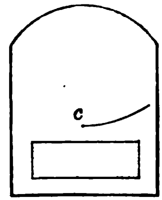

FIG. 69

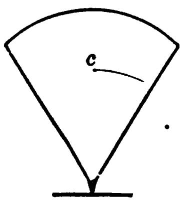

FIG. 70

1. *Stable Equilibrium.* A body so supported that a small disturbance will *raise* its center of gravity, is in stable equilibrium; that is, it will return to its former position as soon as it is free to do so. Fig. 69 shows an example of stable equilibrium.

2. *Unstable Equilibrium.* If a small disturbance *lowers* the center of gravity of a body, so that it tends to take a new position, it is in unstable equilibrium. Any body balanced on a point, with its center of gravity above that point, is in unstable equilibrium (Fig. 70).

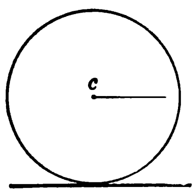

FIG. 71

3. *Neutral Equilibrium.* When a body in moving tends *neither to raise nor lower* its center of gravity, it is in neutral equilibrium. For example, a sphere rolling on a horizontal plane (Fig. 71). Such a body will remain supported upon any point of its surface.

78. Stability. — If one body is less easily tipped over than another, it is said to be more *stable*. A bit of careful thought will show what conditions make one body more stable than another.

We have learned that to "balance" a body it is necessary simply to get *its line of direction inside its base.* We

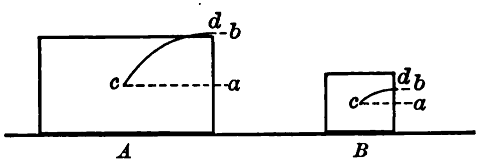

FIG. 72

know it is easier to balance a body on a broad surface than on a small point; also that it is easier to balance a stick or pencil on its side than on its end. Keeping these

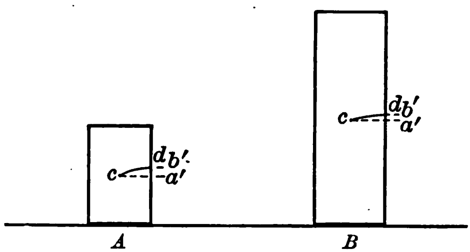

FIG. 73

facts in mind we shall not find much difficulty in understanding the following statement regarding stability:

The broader its base or the lower its center of gravity the more stable a body will be.

Figs. 72 and 73 will help explain why this is true. The body *A*, in Fig. 72, has the same height but a broader base than *A* in Fig. 73; in both figures *c* is the c.g.

The body *B*, in Fig. 72, has the same base but a lower center of gravity than *B* in Fig. 73; here, also, *c* is the c.g. Now in all four figures it is plain that if the body is to be tipped over, its c.g. must move from *c* to *d*; in each case it must rise straight up as far as from *a* to *b* and from *a′* to *b′*. A glance at the figures will show that the distance is greater in *A* and *B* of Fig. 72 than in *A* and *B* of Fig. 73; and as *c* moves the distances *ab* and *a′b′* directly against the force of gravity, *the greater*

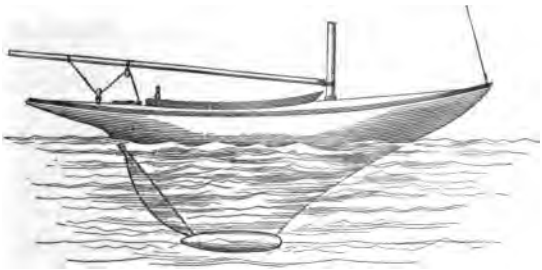

FIG. 74

the distance the more force will be needed. Hence we see that the lower the center of gravity and the broader the base the harder it is to tip a body over.

This principle is important and is commonly used. All sorts of monuments and towers are built tapering upward — partly for beauty, but also to be more stable. In loading furniture on a cart the heavy things are put at the bottom so as to lower the center of gravity. For the same reason the heaviest part of the structure is at the bottom in any building likely to feel high winds or earthquakes; and vessels carry a heavy "ballast" down below the water line. A wide boat is usually safer than

a narrow one, because of its broader base; and the light racing yachts are kept from tipping over by a heavy lump of lead on the keel (Fig. 74), which carries the c.g. far below the water line.

In all cases we must remember that the center of gravity is the center of *mass* (weight) and not necessarily the center of the body itself.

QUESTIONS

1. Define the center of gravity of a body. What is meant by balancing a body?

2. Under what conditions is a body supported from beneath?

3. Is the c.g. always the center of a figure?

4. Is the center of gravity always inclosed in the matter of the body? Where is the c.g. of a ring?

5. Where is the center of gravity of the earth? Is it exactly in the geographical center? Why?

6. When a body is free to move, what position does its c.g. assume? Which end of a falling hammer would be downward?

7. Why is it hard to keep standing if we jump from a height?

8. In what sort of line does the center of gravity of a freely falling body move? What is this line called? What is the base of a body?

9. Through what must the line of direction pass if a body would remain supported? Under what conditions will a body fall?

10. When are two or more forces in equilibrium? What is an unbalanced force? What is the effect of an unbalanced force?

11. Name the three states of equilibrium. Give examples of each.

12. What is meant by the stability of a body?

13. Upon what does stability depend? Is a pyramid a stable body? Why?

14. Why is it more difficult to tip over a low structure than a higher one having the same base?

SECTION V

CENTRIFUGAL FORCE

79. Explanation of Centrifugal Force. — *When a body moves in a curved path, it tends at all points to pull away and go on in a straight line.* If you whirl a stone rapidly about your hand by means of a string (Fig. 75), it tries to pull away all the time. If at any point, *b*, you simply let go, it flies off at once along the straight line *bc*. The force with which all bodies moving in a curved path tend to pull away from that path, is called *centrifugal force.*

The name *centrifugal* (from the Latin words for "center" and "to fly") is given because the bodies seem to pull away from the center of the curve. But it is really no new "force"; it is simply another result of the first law of motion. By that law, we remember, all moving bodies tend to move in a straight line; if now some other force tries to draw such a body in a curved line, it will resist that force with a strength which we call centrifugal force. It is clear, then, that *centrifugal force is due to the tendency of all moving bodies to move in straight lines.*

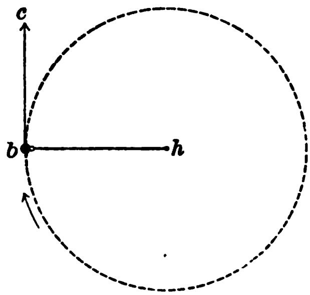

FIG. 75

In Fig. 76, *a* shows a car on a track, *b*. As it moves around the curve its center of gravity tries to go on straight (*cc'*), and the centrifugal force tends to tip the car over.

80. Effects of the Centrifugal Tendency. — Examples of this force are many. We can swing a pail of water rapidly overhead in a circle and not spill a drop. Centrifugal force holds the water, pressing hard against the bottom in its effort to go in a straight line.

Any car, carriage, or wagon in turning a corner feels the effect of this force. If the force is strong enough, it may tip the carriage over. Fig. 77 gives an idea of what centrifugal force has to do in order to overturn any carriage. Let *e* mark the spot where the outside wheel touches the ground, and let *c* be the center of gravity. Now before the carriage can fall over, *c* must be as far over as *d*; this means simply that centrifugal force must be strong enough to lift the weight of the carriage from *c* to *d*.

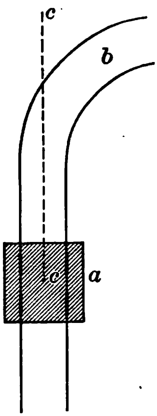

FIG. 76

We know that in riding a wheel, or even in running, we lean toward a corner as we go around it. We do it by experience and habit, perhaps not knowing why. If we sat upright, the centrifugal force would make us fall on the side away from the corner; but by leaning *toward* the corner, our c.g. is lowered so far that the force is not strong enough to lift us. If we are going faster, we lean lower; that is, the greater our momentum the more we have to allow for this force. Also we have doubtless found out that on sharp curves we have to allow more than on gradual turns. Hence the following rule:

The greater the energy of a moving body, or the sharper the curve, the greater the centrifugal force.

On railroads the inside rail is placed lower than the outside in making a curve. Fig. 78 may help to explain the reason. The figure shows a car tipped more than usual to show the point clearly. Dotted lines show where the car would be if both rails were of the same height; *e* is the outside wheel, *c* the center of gravity. If the rails were even, the c.g. would be at *c′*; but as the car is tipped, we can easily see that the centrifugal force will have to lift the car the distance *c* to *c′* in addition to what it would have to do if the car were level.

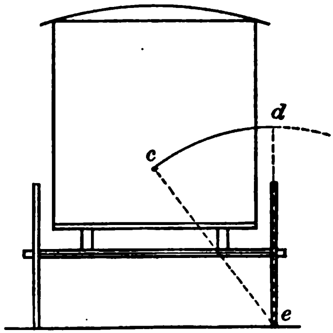

FIG. 77

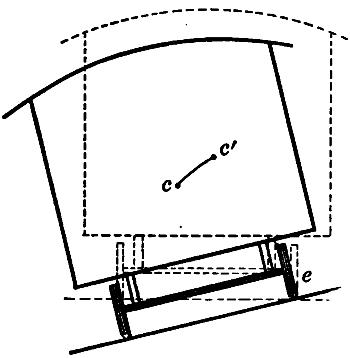

FIG. 78

81. Centripetal Force. — The force which acts to pull a body into a curved path is called *centripetal force.* This word, also from the Latin, means that the force acts *toward* a center. In the case of a stone on a string the hand is the center, and force is exerted along the string, pulling the stone toward this center. Centripetal force would make the stone come straight to the hand; but centrifugal

force also acts at the same time, keeping it out as far as the string will permit.

In connection with this subject we may note that *no body will move in a curved path unless force is being applied all the time.* If for the shortest moment of time this centripetal force ceased to act, the body would go in a straight line.

QUESTIONS

1. What is meant by centrifugal force? Is it really a distinct "force"? To what is it due?
2. Give examples of this centrifugal tendency.
3. Could you swiftly turn a corner if you sat upright on a wheel? In which direction do you lean? Which way would you fall if you did not lean? What is the use of leaning?
4. Upon what does the intensity of centrifugal force depend?
5. Why is the inside rail placed lower on curves in a track?
6. Why do engineers slow down before rounding a sharp curve on a railroad?
7. What is meant by centripetal force?
8. Why should force have to be applied continuously in order to make a body move in a curved path?
9. Show how centrifugal force may be regarded as the reaction of centripetal force.

SECTION VI

THE PENDULUM

82. The Pendulum described. — A *pendulum* is any device so suspended that it is free to swing to and fro about a fixed point.

Fig. 79 shows a pendulum, *a* being its *point of support* (on which it swings), and *b* the weight, or *bob.* As the weight *b* is moved to *c*, gravity acts upon it, pulling

it downward toward the position *e*. When it gets to *e*, however, it has acquired momentum enough to overcome gravity and lift itself to the point *d*. As it moves from *e* to *d*, the weight gradually loses its momentum, till at *d* it has none and gravity pulls it back toward *e*. This goes on several times, the weight moving not quite so far each time, till finally it comes to rest at *e*.

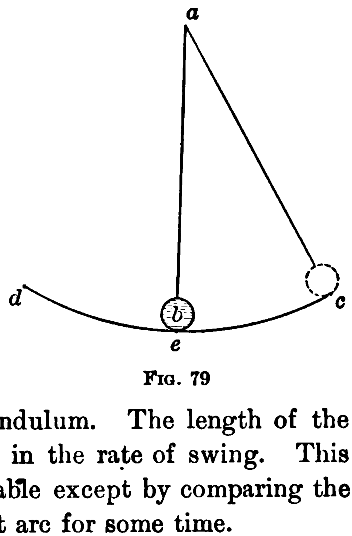

FIG. 79

Note that this is the position toward which gravity was all the time pulling it, and in this position *the point of support is in the line of direction;* that is, a line through *a* and the center of gravity would go to the c.g. of the earth.

The path of the bob (*ced*) is called the *arc* of the pendulum. The length of the arc makes little difference in the rate of swing. This difference is hardly noticeable except by comparing the effect of a long and a short arc for some time.

83. Law of the Pendulum. — Since the motion of a pendulum usually depends upon the force of gravity, it is plain that its rate of swing must be affected by the greatness of this force; and as the force grows less intense with the increase of distance from the earth's center, *the length of time required for each swing* (*i.e.* one *vibration*) *increases as the distance from the earth's center increases.* This, however, is a factor which we do not often need to consider.

The most important point is the *length* of the pendulum. By "length" is meant the distance from the point of support to the center of oscillation (the point where the force seems to be applied). Therefore the fact to be most carefully considered concerns this distance, and may be thus stated:

The greater the length of the pendulum, the longer the time of vibration.

Many clocks have a pendulum to govern the rate of movement of the works. If we want the clock to run slower, we lower the bob a little; if it needs to run faster, we raise the bob. We simply make the pendulum longer or shorter, according as the clock runs too fast or too slow.

QUESTIONS

1. In what position does a pendulum hang when at rest?
2. What is the "arc" of a pendulum? the "vibration"? the "length"?
3. Upon what does the rate of vibration depend?
4. Name uses of the pendulum.
5. Would a pendulum move faster at the equator or at the poles? Would its rate increase or decrease on the moon?
6. How regulate a clock which is too slow?
7. Will a common pendulum swing indefinitely long? What stops it? Why does the pendulum of a clock keep on indefinitely?

SECTION VII

FALLING BODIES

84. Gravity acts equally upon all Bodies. — Long ago we learned the *cause* of falling, we have guessed where falling bodies would go if nothing stopped them, and lately we have found that all bodies tend to fall if the

line of direction passes outside the base. There are just a few more points to be considered.

One of these may for a moment seem strange: gravity tends to make all bodies fall equal distances in equal periods of time. If we drop a small piece of shot and a cannon ball from the same height, they will reach the ground together. True, the cannon ball will have more *momentum*, but that is solely *because of its weight and not its speed.*

The only factor which can make a difference is the air. A piece of paper or a feather slowly flutters down, not because gravity fails to act, but because *the air resists its passage.* All bodies which (like paper and feathers) have a large surface and little weight will be kept from falling fast by the resistance of the air. It is only in a vacuum that we can give this law a fair test. Fig. 80 shows a glass tube from which the air may be removed by an air pump. If we put, for example, a feather and a penny together into the tube, pump out the air and quickly invert the tube, penny and feather will fall side by side. Any other bodies would do the same. From these facts may be derived this statement:

FIG. 80

Gravity acts the same on all bodies, and except for resistance of the air, all bodies fall equal distances in the same length of time.

85. Velocity of Falling Bodies. — Careful study has shown these facts: *Gravity causes a body to fall sixteen feet in one second, and during every second of its fall a body gains a velocity of thirty-two feet per second.*

The last statement means simply that by falling for a second a body gains momentum, which alone will carry it thirty-two feet more. Thus a body having fallen one second starts out on the second second of its fall with a velocity which can carry it thirty-two feet; gravity also acts on it enough to carry it sixteen feet, so that in the second second it travels (32 + 16) forty-eight feet.

Now we can easily see that the falling body is gaining a velocity of thirty-two feet per second during every second of its fall, and losing nothing; therefore *the farther a body falls the faster it goes.* Now the faster a body moves, the more momentum it has; and the more momentum it has, the more force must be used in stopping it. Thus a person is perhaps killed by a fall of fifty feet, while people often fall five feet unhurt.

QUESTIONS

1. Why does a feather or piece of paper fall slowly in an irregular line? In a vacuum how do all bodies fall?
2. How far will a body fall in one second?
3. What momentum does a falling body acquire in each second?
4. How far will a body fall in four seconds?
5. To what extent is the acceleration of a body due to gravity?
6. Why does a fall of sixty feet hurt us more than one of six feet?
7. How far would a body fall during the fifth second of its descent?
8. What would be the velocity of a body at the end of the seventh second of its fall?

SECTION VIII

WORK AND MACHINES

86. Work defined. — *Work is said to be done whenever a force causes motion.* The body which exerts the force is said to do work; the body which moves is said to have work done upon it. If we lift a stone, we do work upon it against gravity; when the stone falls, it is because gravity does work upon it.

87. Measure of Work. — The *amount of work* done is usually expressed in *foot pounds. One foot pound is equivalent to one pound of matter raised one foot against gravity.* If you raise one pound to a height of ten feet, you do (1×10) ten foot pounds of work; if, again, you raise ten pounds one foot high, you likewise do (10×1) ten foot pounds. The same result will be accomplished if you lift five pounds two feet or two pounds five feet $(5 \times 2 = 10;\ 2 \times 5 = 10)$.

It makes no difference how long it takes. For example: if, using a pulley, we raise a barrel of corn weighing two hundred pounds up to a floor fifteen feet higher, we do (200×15) three thousand foot pounds of work; a mouse might carry it up kernel by kernel, — it would take very much longer, of course, but when it was all up, he would have done three thousand foot pounds of work just the same.

Sometimes it is useful to know the *rate* at which work may be done — men frequently want to know how powerful an engine is, for instance. The unit used in

such cases is called a *horse power*. *One horse power represents the ability to do thirty-three thousand foot pounds of work in a minute.*

88. Machines. — A *machine* is a device which helps man in doing work. Machines do not of themselves exert force; they possess no energy, and so *they can only apply such force as is first exerted upon them from without.* For this reason no machine gives us a gain in

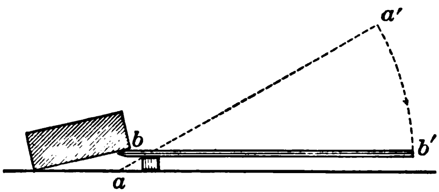

Fig. 81

work. The amount of work is measured by the product of force times distance (§ 87): if, as in Fig. 81, by using a small force we lift a heavy weight or do any heavy task, we find that whereas the weight has moved only a short distance, *ab*, we applied the force through a long distance, *a′b′*.

Not only do machines give no gain in *work*, but they always show some *loss*. Some of the energy is used up in overcoming "friction" in the machine, for no machine is without a certain amount of friction somewhere.

89. Uses of Machines. — Though all machines show some loss of work, they are still of very great advantage to man — mostly to help do his work *more conveniently.* Following are some of the more important uses.

1. *They may be used to change the direction in which force is applied.* Of such machines the pulley (Fig. 82) and some levers (Fig. 83) are most common. In many cases it is inconvenient and sometimes impossible to

apply force to a body in the direction in which we want it to move. At such times a pulley, lever, or some other simple machine may be of great assistance, giving us a chance to apply the force in another and easier direction.

2. *We may use other forces than our own to run them.* Windmills and sailing vessels use the force of the *wind;* engines, pumps, and drills are run by *steam; water power* is used to turn mill wheels and run all sorts of machines; and *electricity* is now being controlled and used by man in many ways. We can easily think of others.

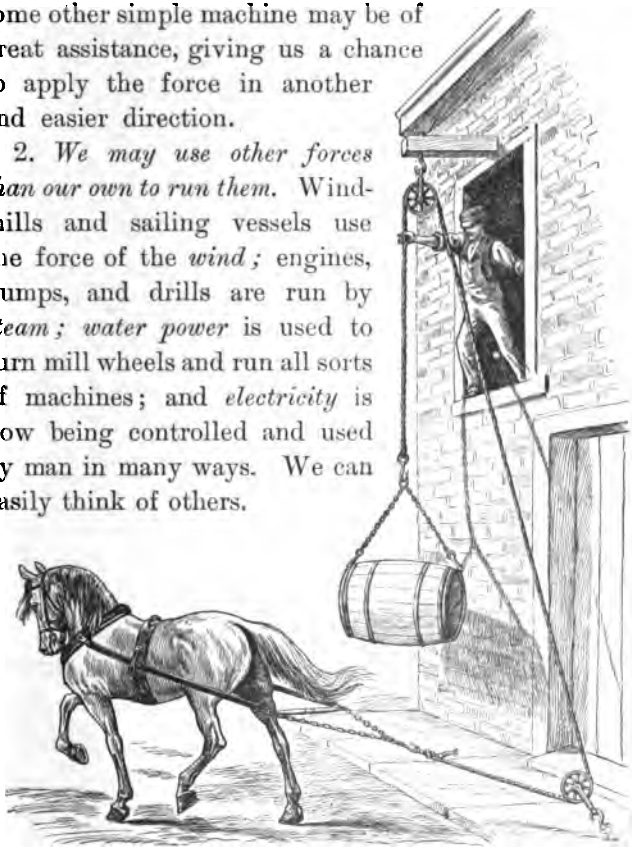

FIG. 82

3. *Man may store up energy in one way or another, to be used more slowly.* For example, when we wind up a watch we simply do work upon the spring and

coil it tightly. As the spring slowly unwinds, the works of the watch are moved and we simply get back little by little the work done upon the spring in winding it.

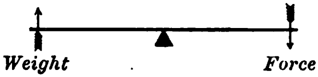

FIG. 83

4. *By using machines we may exchange strength of force for speed, and speed for strength of force.* That is, one can apply much force slowly and move a small body rapidly, or apply a small force rapidly and move a large weight slowly.

Again, we may use a lever to show this fact. If we press down on the end b of the lever ab (Fig. 84), we can raise a weight at a with much less force than if we lift up on the weight itself. But in this case we use the force much more rapidly than the weight moves, for while the force acts from b to b' the weight moves only from a to a'. If, on the other hand, we apply much force at a', we can raise a smaller weight at b'. Here we apply a greater force and move a smaller weight; but the small body, in going from b' to b while the force moves from a' to a, has much greater speed. In the first case we use speed and gain in force; in the second case we use force and gain in speed.

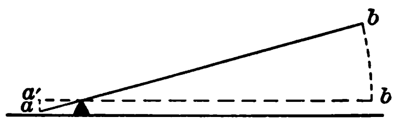

FIG. 84

If, now, we measure the distances aa' and bb', we find that the ratio of aa' to bb' is *inversely* that of the weight at a to the force at b. In other words, if the distance bb' is, for example, five times aa', then the force at b is only one fifth as great as the weight at a.

90. Law of Machines.—The above is only one example, based upon one sort of machine. Other machines have been studied—in fact, all kinds of mechanical devices—and the results are the same in every case. This fact may be stated in words, and as it is true of all sorts of machines we may call it the *Law of Machines.*

The force and the resistance vary inversely as the distances through which the points where they are applied move. Using letters in place of the words, we may represent force by F, resistance by R, the distance through which the force acts by S, and the distance through which the resistance acts by S'.* The law may then be stated as a working *formula*, thus:

$$F : R = S' : S.\dagger$$

Sometimes the word *power* is used instead of "force," and *weight* instead of "resistance." There is no good reason for such use of these special terms, except that it is a common custom. The words *force* and *resistance* are more accurate.

91. The Law applied. — This law of machines may be very easily used in solving simple problems in mechanics. In order to do this it is only necessary to determine from the statement of the problem what factors are given, supply these in place of the letters in the proportion stated above (§ 90), and then solve the proportion. For this purpose the proportion may be written

$$F \times S = R \times S'.$$

* Read "S prime."

† Read "F is to R as S prime is to S."

Problem. With a set of pulleys, a certain force acting through 40 feet of space can raise a 100-pound keg of nails to a height of 10 feet; how great is the force used?

Solution. In this case $S = 40$, $S' = 10$, and $R = 100$; F is to be found, so we say $F = x$.

Applying these figures to the formula, we have

$$\underset{x}{F} \times \underset{40}{S} = \underset{100}{R} \times \underset{10}{S'},$$

that is, $$x \times 40 = 100 \times 10 = 1000,$$

or $$x = \frac{1000}{40} = 25.$$

Therefore the force used is 25 pounds.

Problem. Suppose force, weight, and distance the force traveled were given, to find how far the weight moved.

Solution. Using the formula, we have

$$\underset{25}{F} \times \underset{40}{S} = \underset{100}{R} \times \underset{x}{S'},$$

that is, $25 \times 40 = 100 \times x$, or $100 \times x = 25 \times 40 = 1000$.

Reducing $$100 \times x = 1000;\ x = \frac{1000}{100} = 10.$$

Therefore the weight moved through 10 feet.

Similarly, the law may be used in all such problems.

92. Some Simple Machines. — We cannot hope to make a thorough study of machines in so limited a space of time, but we may take a hasty glance at a few simple machines which are much used.

1. *Pulleys* have been mentioned already. A single pulley is useful only in changing direction, as we learned (§ 89). Two pulleys may be arranged, however, as in Fig. 85. The weight W is attached to B, which is called a *movable pulley.* Now B is held in a loop of the string,

so that as the force *F* moves, the pulley *B* moves only half as far. Thus if the force moves twice as far as the weight, only half as much force is needed. If we had two movable pulleys, the force would be only one fourth the weight; three movable pulleys would decrease the force to one sixth, etc. Movable pulleys are often used in moving great weights short distances.

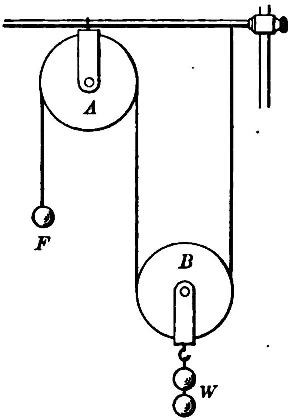

FIG. 85

2. *Levers* are also familiar already, for their use is common. There are *three classes of levers*, according to the position of the point on which the lever turns — the *fulcrum*. Fig. 86 shows the three classes of levers. In each case *p* is the point where the force is applied, *w* the weight, and *f* the fulcrum. Class *II* gives a gain of force, *III* a gain of speed, and *I* a gain of either force or speed according as *f* is nearer *w* or *p*.

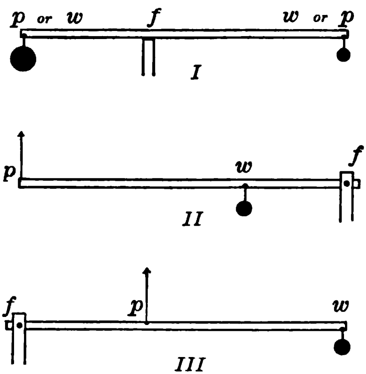

FIG. 86

Special Law of Levers. The part of the lever between the fulcrum and the point where the force is applied is called the *power arm;* from the fulcrum to

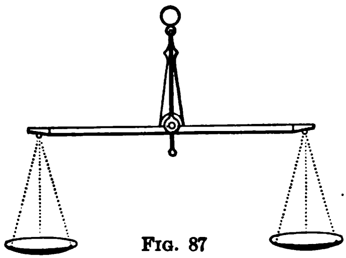

FIG. 87

the point where the resistance is applied is the *weight arm.* Now the distances that f and w must move will bear the same relation to each other as the lengths of their respective "arms." With this in mind we may change the wording of the law of machines to apply especially to levers:

The force and the resistance vary inversely as the lengths of their respective arms.

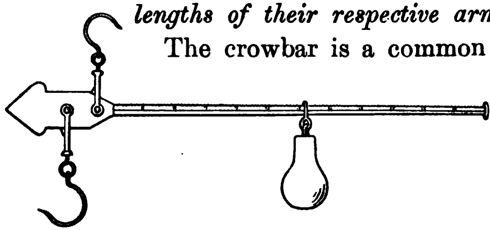

FIG. 88

The crowbar is a common lever. By its use a man can pry up a weight he could never think of lifting with his hands. Common scales make use of the principle of levers; the kind shown in Fig. 87 has the arms equal, and of course gravity will act equally on both. To weigh a body with such scales, we have only to balance the unknown weight in one pan by known weights in the other. Steelyards (Fig. 88) and common grocer's scales have a short weight arm, and a power arm along which a weight is moved on a marked scale. The heavier the body the farther this weight must be taken out on the power arm. Fig. 89 shows

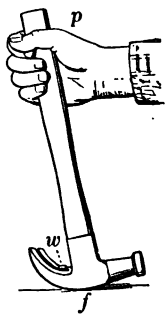

FIG. 89

how a claw hammer acts as a lever. Pincers, nippers, tongs, scissors, etc., all act as levers, the first three giving us a gain in force at the expense of speed. Why do a

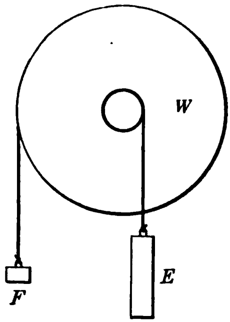

FIG. 90

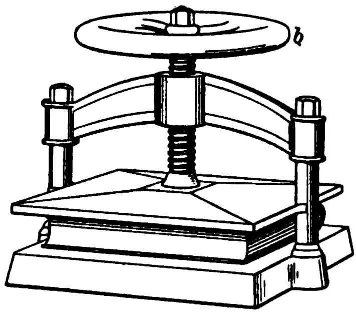

FIG. 91

plumber's shears have short blades and long handles? Why do tailors' shears have long blades and short handles?

3. *The Wheel and Axle* (Fig. 90). A glance at the figure shows that a small force, *F*, applied to the wheel *W*, will move a large weight, *E*, applied at the axle. Also a large force at the axle will cause a smaller weight on the wheel to move more rapidly. The rate of gain in either case would be as the circumference of one wheel is to that of the other. Or they might both be considered as lever arms, each arm being the distance from the center to the circumference.

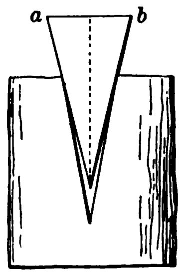

FIG. 92

4. *The Screw.* Fig. 91 shows how the screw may be used to gain intensity of *force.* Here the rate of gain is as the circumference of the wheel *b* to the distance

between two threads of the screw; that is, as the hand turns the wheel once around, the end of the screw moves ahead only the width of one thread. Thus if the circumference of the wheel were fifty inches and the width of thread one-quarter inch, we should have a gain of force of $\left(\frac{50}{\frac{1}{4}}=\right)$ two hundred times.

5. *The Wedge* (Fig. 92). If the wedge were twice as long as it is wide at the base *ab*, for every inch that it

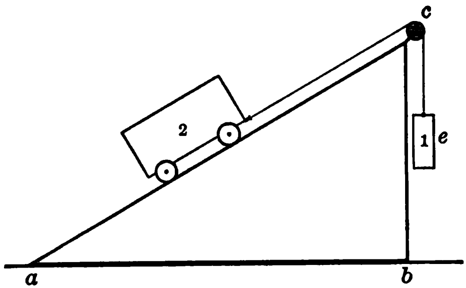

FIG. 93

might be driven into an opening it would have to force the sides only one half an inch farther apart; that is, we should have a gain of *force* at the rate of two units for one.

6. Many other mechanical devices are familiar. A *crank* or *eccentric* may be considered as a wheel and axle or as a lever. The *inclined plane* (Fig. 93) is just the same in principle as the wedge: if, in the figure, the side *ac* is twice as long as *bc*, every pound of weight or force at *e* will balance two pounds on the inclined plane. *Gear wheels* (Fig. 94) are very commonly used

in machinery. The rate of gain in this case would be found just as in the case of the wheel and axle, except that we should count the teeth of the wheels rather than the circumferences.

A little thought will bring to mind many other machines. Some give us a gain of force, some a gain of time or velocity, and many enable man to use other forces than his own. Let us remember, however, that for every gain in one way there is a corresponding loss in some other way. We gain force at the expense of velocity or velocity at the expense of force, but no machine can give out more *work* than has been exerted upon it.

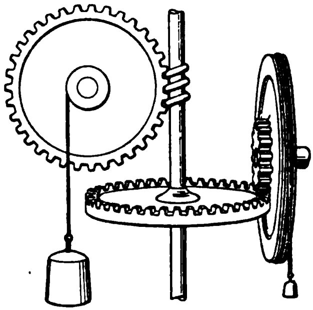

FIG. 94

93. Friction; its Cause.— As we have already learned, some of the force exerted upon a machine is always used up in overcoming the *friction* of its parts. Whenever one surface moves upon another, there is sure to be a small amount of friction at best; unless care is taken to keep the friction as small as possible, the *bearings* will creak with a piercing sound and the parts become badly worn.

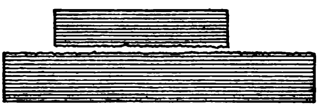

FIG. 95

Fig. 95 may help to explain the cause of friction. No matter how smooth a surface may seem to the touch, no

matter how brightly it is polished, there always will be little projections and little hollows (depressions) all over it. A highly polished surface will, under a strong microscope, show a rough appearance like that in the figure. If two such surfaces move upon each other, *the projections of one keep striking those of the other*, and force has to be used either to flatten the projections or to rise above them. Should the surfaces be pressed together forcibly, the friction would be increased.

94. Remedies for Friction.—Friction may be decreased in several ways. It is common practice to *oil the parts* which move upon each other; oil, being a thick liquid, fills all the hollows and serves to keep the surfaces separated just a little, so that the rough projections of one slide over those of the other without touching. *Polishing the surfaces* also reduces friction, because it wears away some of the greater projections. Friction may be decreased by substituting a *rolling contact* in place of a sliding surface. The familiar ball bearings of a bicycle furnish an example of this method (Fig. 96).

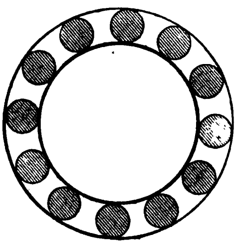

FIG. 96

95. Uses of Friction.—While it surely uses up a great deal of force which might have been put to some better end, there are many ways in which friction is of value to man. For example, we are able to walk because there is friction between our shoes and the floor. If it were not for this friction, instead of going forward

at every step we should succeed only in sliding the foot backward along the floor. Try walking on roller skates, and then remember that even they allow a considerable amount of friction.

Whole shops full of machines are run by an engine which supplies power to a shaft by means of a belt; each machine is connected with this shaft by a belt also. If it were not for the friction between the belt and pulleys on the shaft and machines, the engine alone would run. It is the friction between the parts of rope or string which makes a knot hold strongly. Tie any sort of a knot and then study it; it takes but a moment to discover how friction plays a part.

The brakes applied to car wheels stop the train because of the friction. Matches strike fire when friction is applied; and it is not many centuries since fires were kindled by rubbing sticks together or striking flint and stone.

QUESTIONS

1. What is meant by "work" as a scientific term?
2. What is the unit of work? How much is one foot pound?
3. What is the unit rate of work?
4. How is the power of an engine usually expressed?
5. How much is one horse power?
6. Of what use is a machine to man? Do we gain in work by using machines? How do most machines waste work?
7. Name some of the ways in which machines make labor easier. What forces may be used to run them?
8. Of what use is a coiled spring as a mechanical device?
9. State the Law of Machines.
10. How may a small force be used to do a great amount of work? How may a large amount of work be done in a short period of time?

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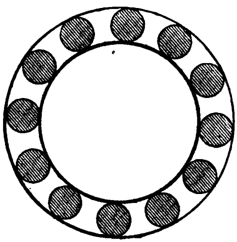

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7. Name some of the ways in which machines make labor easier. What forces may be used to run them?
8. Of what use is a coiled spring as a mechanical device?
9. State the Law of Machines.
10. How may a small force be used to do a great amount of work? How may a large amount of work be done in a short period of time?

matter how brightly it is polished, there always will be little projections and little hollows (depressions) all over it. A highly polished surface will, under a strong microscope, show a rough appearance like that in the figure. If two such surfaces move upon each other, *the projections of one keep striking those of the other*, and force has to be used either to flatten the projections or to rise above them. Should the surfaces be pressed together forcibly, the friction would be increased.

94. Remedies for Friction.—Friction may be decreased in several ways. It is common practice to *oil the parts* which move upon each other; oil, being a thick liquid, fills all the hollows and serves to keep the surfaces separated just a little, so that the rough projections of one slide over those of the other without touching. *Polishing the surfaces* also reduces friction, because it wears away some of the greater projections. Friction may be decreased by substituting a *rolling contact* in place of a sliding surface. The familiar ball bearings of a bicycle furnish an example of this method (Fig. 96).

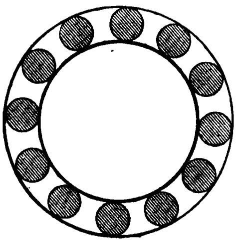

FIG. 96

95. Uses of Friction.—While it surely uses up a great deal of force which might have been put to some better end, there are many ways in which friction is of value to man. For example, we are able to walk because there is friction between our shoes and the floor. If it were not for this friction, instead of going forward

at every step we should succeed only in sliding the foot backward along the floor. Try walking on roller skates, and then remember that even they allow a considerable amount of friction.

Whole shops full of machines are run by an engine which supplies power to a shaft by means of a belt; each machine is connected with this shaft by a belt also. If it were not for the friction between the belt and pulleys on the shaft and machines, the engine alone would run. It is the friction between the parts of rope or string which makes a knot hold strongly. Tie any sort of a knot and then study it; it takes but a moment to discover how friction plays a part.

The brakes applied to car wheels stop the train because of the friction. Matches strike fire when friction is applied; and it is not many centuries since fires were kindled by rubbing sticks together or striking flint and stone.

QUESTIONS

1. What is meant by "work" as a scientific term?
2. What is the unit of work? How much is one foot pound?
3. What is the unit rate of work?
4. How is the power of an engine usually expressed?
5. How much is one horse power?
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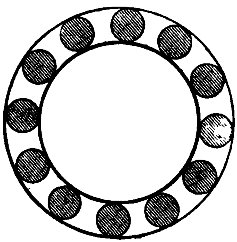

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9. State the Law of Machines.
10. How may a small force be used to do a great amount of work? How may a large amount of work be done in a short period of time?

11. What is the gain by using a single pulley? What the gain from a movable pulley? How may the gain be found in the case of any movable pulley?

12. How many classes of levers are there? Describe each. What is the gain with each?

13. State the special law of levers.

14. Name different uses of levers; different single machines which apply the principle of the lever.

15. Why is it easier to break a long stick than a short one?

16. How may we find the rate of gain with a wheel and axle?

17. Where would you take hold of a wheel to turn it against a great force? Where grasp a hammer to use it most forcibly?

18. What sort of gain does a screw give us? How may the rate of gain be found?

19. What use is made of a wedge? How measure the rate of gain?

20. What sort of machine is a crank? What use is made of cranks or eccentrics?

21. What use is made of gear wheels? of the inclined plane? Does a wheel of high gear run harder or easier than a low gear? Why?

22. Explain the cause of friction.

23. How may friction be decreased?

24. Explain how oiling decreases the friction of two surfaces.

25. How does friction assist in walking? in running machinery? in making knots? in retarding motion? in generating heat?

CHAPTER IV

HEAT AND ENERGY

SECTION I

WHAT HEAT IS

96. Theory of Heat. — According to the molecular theory the molecules of any body are in a state of constant vibratory motion. In our study at the time we passed over that statement, leaving it to be considered later. We may now recall the subject and see how it has been applied by some physicists to explain the subject of heat.

It is fair to suppose that in different substances and under different conditions the molecules may vary in their rapidity of motion. The theory of heat may be briefly stated as follows:

The heat of a body is due to the motion of its molecules; when they vibrate rapidly the body is warmer than when they move more slowly.

Let us apply this theory to a few simple cases and see whether or not it seems to furnish a good explanation. If we file the end of a nail for a minute, it gets hot; why? The theory is that, by filing, the molecules of the nail have been set in more rapid motion. Pound a piece of iron with a hammer for a minute and

it becomes warm; why? By pounding we have set the molecules in more rapid motion. Rub a smooth surface with the hands; here again heat is produced, and we say it is because we have made the molecules move faster. In each of these cases we find an easy explanation in the theory of heat, and it seems reasonable as well.

97. Cold. — The question naturally arises, What is cold? Let us think a minute about the answer. In summer we say ice water is very cold; but some day in winter, when the thermometer is down near zero, you come in with your fingers stiff from cold, and the ice water then feels warm. Which is it, warm or cold? Another example: in summer if the thermometer stands at 40° F. we think it is cold, while 40° would seem a warm relief after a cold week in winter. These examples are enough to show that "cold" depends very much on the point of view.

And now we are ready to learn that *cold is simply the absence of heat.* We *say* a body is cold when it has less heat than some other body with which we are comparing it; but there is always some heat in such a body. If a substance were strictly *cold*, there would be no heat in it — *no motion of its molecules.* Scientists have been able to produce some very low degrees of heat, but no body has ever been cooled down till there was *no heat* in it, so far as men know.

98. Sources of Heat. — The source of heat on earth is the sun; for without the sun's light and heat we should not have wood, coal, oil, and other things which are to-day used as fuel.

There are many minor sources of heat commonly used; friction, chemical action, electric currents, etc., are examples.

QUESTIONS

1. How is heat explained by the molecular theory?
2. In what condition are the molecules of a hot body?
3. Explain how friction may make a body warmer.
4. A lead bullet which has just struck a target is warm; how may this be explained?
5. What is meant by cold? Is a body ever thoroughly cold?
6. What would be the condition of the molecules of a perfectly cold body? Has this condition ever been reached?
7. What is the source of heat on earth?
8. Show how, when wood is burned, we get only the heat which once fell upon earth from the sun. Do the same with coal. Name other sources of heat.
9. Name other ways in which heat may be generated.

SECTION II

TRANSFER OF HEAT

99. Three Methods of Transfer. — Substances may be heated from other bodies in three different ways, — radiation, convection, and conduction.

100. Conduction. — *Conduction is the flow of heat from one body to another, or from one part of a body to another, when the bodies or parts touch each other.* This flow of heat goes from a warmer to a cooler part.

A body which allows the heat to travel along through it is called a *conductor.* There is a great difference in conductors, some being very good, others so poor as to

seem to allow no heat to pass through them. The metals are usually good conductors, but among them there is a great difference in conducting power. Fig. 97 shows a board with equal lengths of four different kinds of metal wires. Hold the ends, *A*, in a flame, and we shall notice a great difference in the time it takes each wire to get hot at the other end.

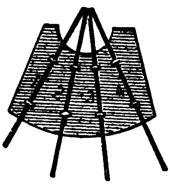

FIG. 97

In general, solids are better conductors than liquids, and liquids are better than gases. Hold a tube full of water in a flame so that it will boil at the top (Fig. 98). We can hold it some time before it gets hot enough to pain the hand. A bar of metal (iron, for example) of the same size would be hot before the tube of water began to feel warm. Water is not so good a conductor as the solid iron.

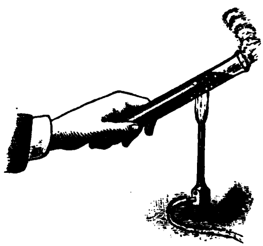

FIG. 98

If we put our hands in water that is just the same temperature as the air around it, the water seems much colder. This is because it is a better conductor than the air and so takes heat out of the hands more rapidly. Air is a very poor conductor; in fact, when air is perfectly dry it is hard to discover that it conducts heat at all. Wood is also a poor conductor. Many stove lifters and pokers have wooden handles because the wood does not easily become hot.

101. Explanation of Conduction. — Conduction is explained in this way. When part of a body is heated,

the molecules at that place move much more rapidly. Of course they hit harder and faster upon those next to them, till in time they too move as rapidly as the first ones. In this way the motion is carried to the next molecules, and then to the next, and so on. If the first part be heated long enough, this heat may in time be carried over the whole thing. Also, if the hot body touch another, the motion of the molecules will be transferred, and the other body become heated by conduction.

102. Radiation. — The transfer of heat by *radiation* is of greatest importance. We have only to learn that this is the method by means of which the earth receives heat from the sun, to realize how much depends upon it.

Exactly how heat is transferred by radiation is not definitely known, because the medium through which the radiations travel cannot be discovered by man. This medium is called *the ether;* so far as we know, it has none of the properties by means of which matter is commonly known to us, yet it is assumed to be *exceedingly elastic* and to fill all space — even the pores between molecules. Through this medium *radiations* travel at a very rapid rate, *without heating the medium itself.* It is well known that at higher altitudes above the earth's surface intense cold prevails, and passing out into space (even though we were nearer the sun) we should doubtless find a condition of unbearable cold. When these radiations fall upon certain bodies of matter, however, they may increase the heat of those bodies. Thus the radiations that do not heat the ether,

and often not even the air through which they pass, may fall upon the earth and there produce a marked degree of heat. The effect produced by radiations varies in different substances; in some kinds of matter they give rise to a greater degree of heat than in others, while upon a few substances their effect is very slight.

Other bodies besides the sun may give off heat by radiation. The subject is further treated in § 205.

103. Convection. — We have seen that air and other gases are such poor conductors that they can hardly be heated in this way. We know, however, that the air in a cold room does become warm very quickly if a hot fire is built; and this gives evidence of still another method, the last of the three. *In liquids and gases, which move freely, the heated parts rise to the top while the cooler parts sink to the bottom: this is called convection.*

The reason is simple. When a liquid or a gas is heated, it expands (that is, takes up more room); therefore *the same volume of it would weigh less.* Thus the cooler substance around it, being heavier, crowds down upon the heated part and *forces it up.* In this way, as soon as the air in a room becomes heated over a stove it rises; colder air falls in to take its place, and this in turn gets hot and rises. In a short time all the air in the room will have moved about in this manner, and the whole will be warm.

104. Some Uses of Convection. — Convection is an important method of heating, and examples of it are very common. Often in winter a room may be fairly

warm, though near the floor our feet feel cold; if we stand on steps so that our heads are near the ceiling, we find it at the same time uncomfortably warm there. This is because the hot air rises and the cold air sinks.

A kettle of water on a stove is warmed by the aid of convection. The lower layers are heated from the fire; being heated, they are lighter and rise to the top. The colder water falls to the bottom to be heated and rises in time to the top also. In this way all the water is soon hot — in much less time than it would have been heated by conduction.

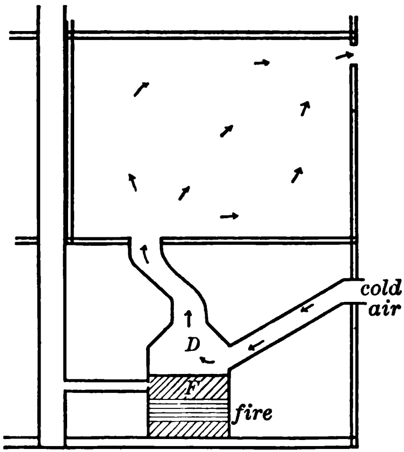

FIG. 99

Fig. 99 shows how houses are sometimes heated by a *hot-air furnace*. In the figure, F is the furnace, and on its top is a hollow dome, D, where the air is heated. A glance at the figure will show us how fresh air comes in from out of doors, is heated in the dome D, and then goes up into the room warm and fresh. The air is kept going in the direction of the arrows by convection; the cold air from the outside pushes upon the lighter warm air in the dome and forces it up. *Hot-water heaters* are sometimes used, and they work in much the same way. Pipes full of water run all over the house;

the water in them is heated by a furnace at the bottom and runs up to the top by convection. In both these cases notice that the furnace must be at the bottom; why?

Fig. 100 shows how a *lamp* makes use of convection. In order that any fire shall burn there must be a good *draught;* that is, a current of *fresh air must be constantly brought to the burning substance.* In the figure, *f* is the flame and *b* the burner, with holes through which air can pass to the flame. The air in the chimney is heated by the flame and rises; this causes a partial vacuum in the chimney, and air rushes in through the burner to take its place. In this way a draught is caused and the flame is supplied always with fresh air.

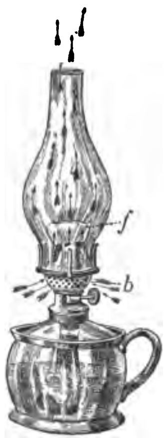

FIG. 100

The same principle is applied to a *stove*, as shown in Fig. 101. The air above the fire, *a*, is heated and rushes up the chimney *p*. Air from the outside then enters through the draught *d* and supplies the fuel *c* with what it needs. A fire may be made to burn more slowly by partly shutting off this air current, by means of draughts and dampers.

The great trade winds, monsoons, and in fact all *winds*, are caused in the first place by convection. Air over some warmer place gets heated and rises; the air all about rushes toward that spot, and this causes a general movement of the air which we call wind.

These are only a few examples from the many with which we are very familiar, but they serve to

give some idea of the importance of this subject of convection in common matters.

105. Ventilation. — The problem of supplying rooms and buildings with fresh air is called *ventilation.* Various methods make use of convection to accomplish the result.

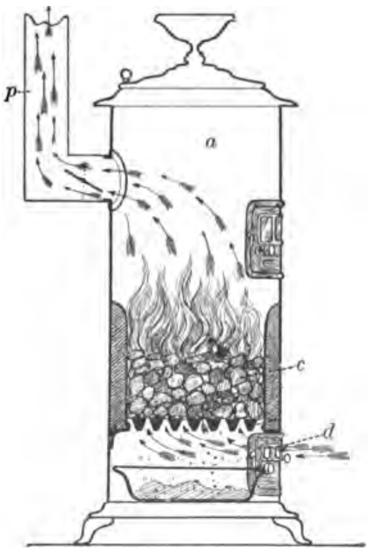

FIG. 101

We have seen (§ 104) how the *hot-air furnace* serves this purpose, supplying warm, fresh air. Unfortunately many of them do not provide for removing the old air from the building. Steam and hot-water heaters also have this same defect, and even a worse one. For where the "radiators" are in the rooms the air is heated, but no provision is made for supply or removal. Some systems of *steam heat*, instead of sending steam to each room, have coils of pipe inclosed in large air boxes. These boxes admit fresh air from out doors, heat it by contact with the steam pipes, and allow it to rise in big pipes to the rooms.

Stoves, as shown in § 104, serve as ventilators by keeping a supply of warm air going up the chimney (Fig. 101). A supply of air must force its way into

the room to take the place of that passing out. *Open fireplaces*, working similarly, are very effective. They are often used in large buildings simply to secure ventilation.

Ordinary *gas stoves* or *oil stoves* are very unhealthful as heaters, unless connected with a chimney which will take the vitiated air out of the room. They do not serve as *ventilators* at all; and worse, they turn the impure air back into the room. Much of the *oxygen* of that air has been used in the burning, and its place is taken by *carbonic acid gas*. Air containing much of this gas is quite unfit for use. *Coal stoves*, if not properly regulated, may give off another gas which is distinctly a poison. Hence the danger in coal stoves.

106. How Substances are cooled. — We have learned that when one body is heated from another it takes on something which makes its molecules move faster. But inasmuch as the one body *takes on* heat, the other body *parts with* some of its heat — the molecules of the one increase their motion, while those of the other lose some of theirs. A body cannot give heat to another without becoming just so much colder.

Now it may be recalled that cold is simply the absence of heat (§ 97). Therefore *the only way in which we can cool a body is to take heat out of it*. This is commonly done by putting it near some other body which is colder than itself. When any two bodies are brought near one another, *heat seems to flow from the warmer to the colder till both have the same temperature*. Thus ice cools things near it because they, being warmer, send some of their heat into the ice.

QUESTIONS

1. In what ways may heat be transferred?

2. How is heat conveyed by conduction? What is a conductor?

3. Are all substances equally good conductors?

4. How do solids, liquids, and gases compare as conductors?

5. Why are pokers and cover lifters provided with wooden handles at times? Why are steam and water pipes usually covered with thick felt?

6. What is the difference between heating by conduction and by radiation? How is the earth warmed from the sun? How is the air warmed? Will the sun's rays heat through glass?

7. What is it that travels from the sun to the earth? Is the space between the earth and the sun warm?

8. Describe convection. In what states of matter is convection possible?

9. Explain the process of heating by convection.

10. In what part of a room is air usually warmest? Why?

11. Show how convection may serve to give a good draught for a fire. Why does blowing down a lamp chimney extinguish the flame?

12. What is the difference between heating by conduction and by convection? Which would more quickly heat a kettle of water?

13. Show how winds are caused by convection.

14. Why does water feel colder than the air at the same temperature?

15. How is any body cooled? By what means is this usually done?

16. Explain how bodies are cooled by the use of ice. What becomes of the ice as a result?

17. Would ice melt if it could get no heat?

18. What is meant by ventilation? What is the need for fresh air? Why are gas and oil stoves harmful in a room?

19. Show the advantage of open fireplaces. The disadvantage of steam and hot-water heaters. What danger is there in coal stoves?

SECTION III

TEMPERATURE

107. Definition. — *Temperature means simply the condition of a body as regards heat and cold.* If a body is warmer than another, we say it has a *higher temperature;* if it is colder, we say it has a *lower temperature.*

Let us note carefully that the "temperature" of a body does not mean the *amount* of heat in it. A spoonful of water may have the same temperature as a pailful, yet the amount of heat in the pailful would be far greater. Temperature is just an expression of the *average heat of each particle* of a body — it does not matter how many particles there may be.

108. Thermometry. — A *thermometer* is an instrument for measuring temperature. It does this *by expressing, in "degrees," how much warmer or colder a body is than some other substance which is taken as a standard.* This may best be explained by describing the two kinds of thermometers which are in most common use.

The *Centigrade* thermometer is used mostly in scientific work. The standard in this case is *freezing water*, and is marked *zero* (0) on the scale. The temperature of *boiling* water on that scale is marked one hundred (100). The space between 0 and 100 is divided into one hundred parts, each one of which is called a *degree* and is written thus, °. So if the thermometer shows a temperature of 60°, we know the substance is sixty degrees warmer than freezing water.

The *Fahrenheit* thermometer is the one most commonly used in everyday life. The zero temperature on this scale is a mixture of ice and salt, and of course it is marked 0. The temperature of freezing water, which was 0° on the Centigrade scale, is 32° above zero. The temperature of boiling water is 212°. So we see that the degrees on the Fahrenheit scale are smaller than on the Centigrade.

Fig. 102 shows the two thermometers and the difference between them. Zero on the Centigrade is the same as 32° above on the Fahrenheit, and 100° on the Centigrade is the same as 212° on the other. The Fahrenheit thermometer is named from the man who first made it. The Centigrade scale is so called because it is based on the number one hundred.

Perfect cold has never been reached, but men who have studied the subject much have calculated that we should have *absolute cold* at 273° below zero on the Centigrade scale, or – 459.4° Fahrenheit. Absolute cold would, of course, mean that there was *no heat at all* in the body; that is, all the molecules would be at rest.

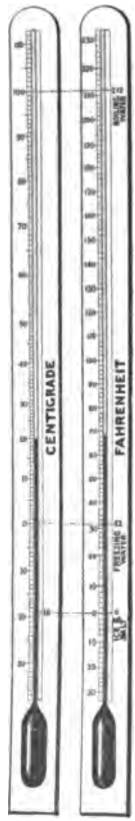

FIG. 102

109. Construction of the Thermometer. — To make a thermometer, a very small tube of glass, having a fine, hairlike bore and blown into a bulb at one end, is partly filled with mercury. The

tube is completely closed, and *the air is removed* so it will not press upon the mercury. The glass is usually put on a piece of metal, which is marked in a scale to show the degrees.

The action of the thermometer depends upon a principle we shall soon study, — *expansion*. When the mercury is in a warm place it expands (that is, grows larger) and so rises higher in the tube; when cooled it simply shrinks back again to its former size. If cooled more, it keeps on growing smaller and falling lower in the tube.

To mark the scale. If it is to be a *Centigrade* scale, first put the tube in melting ice and mark the place where the mercury stands 0°. Next put it into water which is boiling freely in an open dish, and mark the point where the mercury then stands 100°. The space between would be divided into one hundred degrees. If it is to be a *Fahrenheit* scale, mark it 32° when it is in melting ice, and 212° when in boiling water. The space between would of course be divided into (212 − 32) one hundred and eighty degrees.

In some thermometers *alcohol* is used in place of mercury; the alcohol is often colored red so that we may see it plainly. Mercury becomes solid at 39° below zero, so it cannot be used to measure very low temperatures.

QUESTIONS

1. What is the difference between temperature and quantity of heat? How is temperature expressed?

2. What is a thermometer? Describe it.

3. What two sorts of thermometers are most common? On which are the degrees longer? Which is more commonly used by the people in general?

4. How is the point zero found on the Centigrade scale? on the Fahrenheit?

5. What is the freezing point of water on each? the boiling point?

6. How many degrees Fahrenheit between the freezing point and the boiling point of water? How many degrees Centigrade?

7. How change a Centigrade reading to Fahrenheit? Fahrenheit to Centigrade? How many Fahrenheit degrees equal one Centigrade degree?

8. What liquid is commonly used in thermometers? What is used for low temperatures? Why?

9. Upon what principle does the height of liquid show the temperature of air?

SECTION IV

QUANTITY OF HEAT

110. The Calorie; Definition. — The distinction between temperature and quantity of heat need not again be discussed (§ 107). Enough to say that it is commonly desirable to express in numbers the total *amount of heat* in a body, and for this measurement a unit called the *calorie* is used.

One calorie is the quantity of heat needed to raise the temperature of one kilogram of water one Centigrade degree.

111. Heat Capacity. — If equal masses of iron and water be heated under exactly equal conditions, it will be found that in the same length of time the iron will become much warmer than the water. In other words, it takes *more heat* to raise the temperature of water one degree than to produce an equal change in the iron.

A similar difference might be found if almost any two substances were taken; showing that under the

same conditions one substance may have to be heated longer than another to have an equal change of temperature. The *amount of heat* required to change a given mass of any substance a certain number of degrees is called the *heat capacity* of the substance.

112. Specific Heat. — The heat capacity of any substance may be measured by expressing in *calories* the quantity of heat needed to raise one kilogram of the substance one Centigrade degree.

The *specific heat* of any body is the ratio of its heat capacity to that of *water*. Of course in such a case the specific heat of water would be regarded as 1. To say that the specific heat of iron, for example, is .11, would mean that to raise the temperature of a kilogram of iron one degree would take only .11 as much heat as to raise the temperature of a kilogram of water one degree.

113. Loss of Heat by Different Bodies. — Substances of high specific heat (*i.e.* those which warm up slowly) also seem to retain their heat longer. It is not strictly true that they "retain their heat longer," but having absorbed more heat in warming up, they naturally *have more heat to lose* in cooling and more time is consumed. Hence we may say that *substances which have large heat capacity not only need more time in which to reach a certain temperature, but take a longer time in cooling again.*

114. Heat Capacity of Water. — Water affords many examples of the last statement (§ 113). Its specific heat (1.) is almost the highest of any known substance. We have compared the heating of water with iron; compare

the rates at which they cool off. A kilogram of iron heated to 100° C. (boiling water) would be cool before the same amount of water had lost a sensible amount of heat. Hot-water bottles hold their heat for several hours.

Owing to its great capacity for heat, water is an important regulator of *climate*. It becomes warm much more slowly than the land, hence remaining cool until far into summer; and as it cools off slowly, it often keeps warmer till winter is well along. Thus the places bordering oceans usually have a more even climate than those far inland.

QUESTIONS

1. What is the unit for quantity of heat? How much is it?
2. What is meant by the heat capacity of a substance?
3. Define specific heat. What is the standard?
4. What substance has very high specific heat?
5. Why do some substances cool more quickly than others?
6. Explain the effect of the ocean on the climate of places near it.
7. Why should sea breezes in summer be cool winds?
8. How may we find the specific heat of any substance?

SECTION V

EFFECTS OF HEAT: EXPANSION AND CONTRACTION

115. Expansion and Contraction. — When a body, without having any material added to it, grows larger or "swells," it is said to *expand;* when, without losing any material, a body "shrinks" or grows smaller, it is said to *contract*. As a general rule, *a body will expand when heated and contract when cooled.*

Fig. 103 shows a ring and ball, so made that the ring easily fits the ball. If the ball be heated over a flame, it expands and becomes so large that it cannot possibly be pushed through the ring. If allowed to cool for a few minutes, it contracts and again fits the ring. If both ring and ball be heated together, they still fit as before.

A blacksmith in fitting a tire to a wheel usually heats the tire before he puts it on. Upon cooling, it contracts and fits the wheel very closely. In making boilers, steel bridges, etc., the rivets are put in place when they are red hot; cooling, they contract and bring the parts tightly together. In making bridges or any large metal structure, allowance has to be made for expansion and contraction in summer and winter. If you look at the rails on some well-built track, you may notice that in winter there are spaces between the ends of any two adjacent rails, while in summer the rails are expanded and the ends come close together.

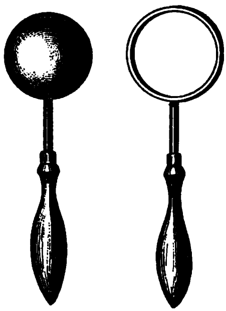

FIG. 103

116. Inequality of Expansion. — *In general, the more a body is heated the more it expands; but different substances vary greatly in the amount which they increase when heated.* Fig. 104 shows two bars of different metals (*e.g.* copper and iron). If heated equally, one of them will grow a trifle longer than the other.

Sometimes different parts of a body may expand unequally; that is, one part may be heated more than

another and so expand more. We have all seen stove covers that have been warped by this uneven expansion. Lamp chimneys sometimes break because of this: one part near the flame may be heated so much more and expand so much faster than another part near it that the chimney is cracked at that point. In the same way cold water thrown on a hot chimney causes it to contract so quickly at one point that the chimney will be likely to crack there.

FIG. 104

117. Expansion in Fluids. — *Liquids and gases also expand and contract as well as solids.* To prove this, take any liquid you please, fill some vessel just exactly full of it, and then apply heat. As it warms up, the liquid will expand and some of it will run over the top of the vessel.

To prove it for gases, fill a flask, *f* (Fig. 105), with any gas (*e.g.* air) and cork it tightly; then run a tube through the stopper and down into a vessel of water, *b*, as in the figure. Apply heat to the gas in the flask. The bubbles escaping from the end of the tube in the water will prove that the gas has expanded. If the flask be held where it is and the gas allowed to cool, water will rise in the tube, showing that the gas contracts on cooling.

It is due to this expansion, as has been said before, that heated liquids and gases are lighter than cooler ones; and this, we remember, is the cause of convection (§ 103). Let us try to understand *why* a heated liquid or gas should be lighter. Of course, if we put

a quart of cold water in a two-quart pail and heat it, we do not change its weight. If, however, we pour that hot water back into the quart measure, we find that we cannot get it all in; *the heated water has expanded so that there is now more than a quart of it.* This shows that in a quart of hot water *there is not so much matter*

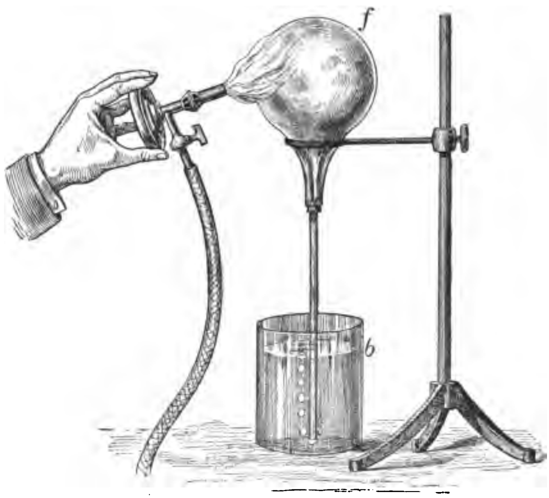

FIG. 105

as in a quart of cold water, and we see at once why hot water weighs less. The same thing is true of all liquids and gases.

118. An Exception to the Rule. — *Water* shows an exception to the rule that heated bodies expand and cooled bodies contract. We have, perhaps, seen blocks of ice floating on water. In order to float, it must of course be lighter than the liquid; and as ice is only

frozen water, it is clear that in freezing the water has expanded. If we fill two bottles with water, cork them tightly, and then heat one, allowing the other to freeze, both bottles will be broken. This shows that in each case the water has expanded. Careful study has shown that *water has its greatest density at 4° above zero Centigrade* (or about 39° Fahrenheit). If it be heated above or cooled below this temperature, in either case it expands.

A few other substances show a similar disobedience to the general rule for expansion and contraction.

QUESTIONS

1. What is meant by expansion? contraction?

2. In general, what is the rule regarding expansion and contraction due to heat?

3. State examples and uses of contraction and expansion.

4. Do all substances expand equally under like conditions?

5. State some results of unequal expansion or contraction in a single body.

6. How may it be shown that liquids expand on being heated? How shown for gases?

7. Explain why a heated liquid or gas is lighter. Suppose a certain quantity of air or water be put in a bottle and tightly closed; will it be lighter if heated?

8. What substance shows an exception to the general rule of expansion and contraction? Is hot water lighter than cold water? At what temperature is water most dense?

SECTION VI

EFFECTS OF HEAT; CHANGES OF STATE

119. Liquefying. — In connection with the three states of matter we learned that substances are sometimes changed in state by the influence of heat (§ 4). Solids change to liquids and liquids to gases when heated; gases become liquids and liquids change to solid bodies when cooled. The change from a solid to a liquid state is called *liquefying*, or *liquefaction;* changing from a liquid to a solid form is called *solidifying*, or *solidification.*

The temperature at which these changes may occur varies widely in different substances; thus at ordinary temperatures many examples may be found of each of the three states of matter.

The temperature at which any solid changes to a liquid is called its *melting point.* Any substance, under the same condition of pressure, *solidifies at the same temperature at which it melts.* For example, the freezing point of water is 0° C.; if we test the temperature of melting ice, we find it to be 0° also. That is, if a liquid is cooled to a certain temperature, it solidifies; if the solid form of the same substance be heated to the same temperature, it melts. This will be better understood a little later (§ 140); for the present it will be well simply to try and fix the fact in mind.

120. Vaporization. — *Vaporizing* is the changing of a liquid into a gas. The temperature at which this change takes place in a substance is called its *boiling point.* We

are familiar with boiling water, for example, and know that before the water can boil it must first be heated to a certain temperature; after that it rapidly changes into a gas (steam) so long as heat is applied. As it boils, the liquid slowly grows less in quantity; and if the heat were still applied, it would entirely "boil away." Of course we need not be told that the water has simply changed its state and gone off into the air.

Pressure upon a liquid makes its boiling point higher; that is, *if the pressure upon a liquid be increased, the whole must be heated to a higher temperature before it will boil.* For example, the water in a locomotive boiler is under great pressure from the steam which is pent up with it. If, now, we test the temperature of the water in that boiler, we shall find it to be much higher than 100° C.

Similarly, *if the pressure upon a body be decreased, its boiling point will be lowered.* Any liquid in an open dish is under pressure of the atmosphere, which of course amounts to fifteen pounds on every square inch of its surface. Sometimes it is desired to boil a liquid at a lower temperature; and this may be easily done by putting it in a closed dish and removing the air. A vacuum would then be formed in the dish, and the pressure on the liquid would be almost all taken away. In making sugar the syrup is usually boiled in these "vacuum pans," because if done in the air the temperature would have to be higher (on account of greater pressure) and the sugar would burn.

121. Evaporation. — The process of changing a liquid to a gas is sometimes called *evaporation*. There is a

certain difference in meaning, however, between evaporation and boiling. Before it can boil, a liquid has to be heated to a certain temperature; the substance may *evaporate* slowly at a much lower degree. It is not even necessary that the substance be in liquid form, for we know that snow and ice will evaporate somewhat, even on a cold day. It may be convenient to regard evaporation as *that form of vaporization which goes on quietly, without a necessarily high degree of heat.*

If you put some water in a plate, leave it a few days, and come back, you find the water has gone. Some one says that it has *evaporated;* what does it mean? Simply that the water was slowly and quietly changed into *vapor*, and this was *absorbed* by the air. It rains, and much water collects on the ground; then it clears and soon the water is gone — where? Some of it drained off, but a great deal evaporated and was absorbed by the air. We wet our shoes, but soon they dry; what became of the water? It simply went into the air in the form of vapor. Let us notice, then, that when a liquid is evaporated it is not destroyed, but simply goes into the air as a gas or vapor.

122. Conditions which assist Evaporation. — There is a limit to the amount of vapor which the air can hold. This limit depends partly upon the temperature of the air; *the warmer the air the more moisture it can hold.* We know that hot air dries things faster than cold air; mud in the streets disappears more quickly on a bright, warm day; we put our wet shoes and garments in a warm place to dry them more rapidly. These things

are so because warm air can hold more moisture than cold air, and it absorbs the moisture more quickly.

Evaporation is also hastened by two other factors,—*the dryness and the motion of the air.* It is easy to see why *dry* air should help evaporation, for if the air already contains as much moisture as it can hold, of course it will not easily take in more. Many hot summer days are not good drying days, because the air is so full of moisture ("muggy").

The way in which *moving* air helps evaporation is simple. Suppose a wet cloth hangs in very calm, still air; as fast as the water evaporates it goes into the air right around the cloth, till that gets so full of moisture that it will take no more. But if a breeze is blowing, it takes away that air as fast as it gets moisture-laden, bringing other air to fill its place. In this way the cloth is kept surrounded by *fresh, dry air*, until all the water has evaporated. We know that windy days are usually better drying days than quiet ones. We know, too, that we sometimes blow on wet ink, our hands, or some other wet surface in order to dry it more quickly.

The best conditions for evaporation, then, would be warm, dry currents of air. In addition to these, the facts may be mentioned that *some substances evaporate faster than others*—that is, the character of the substance makes a certain difference; also that the rate of evaporation is hastened by *increase of surface* exposed and by *decrease of pressure.*

Liquids which evaporate quickly are said to be *volatile.* Ether, kerosene, naphtha, alcohol, gasoline, etc., are examples.

123. Humidity. — It has been shown that a certain volume of air can hold only a certain amount of water vapor. Air which contains a great deal of moisture is said to be *humid*. When a volume of air contains every bit of water vapor that it can hold, it is said to be *saturated*.

124. Condensation of Moisture. —*In any certain temperature of air, there is a definite amount of water which may be held in the form of vapor.* With this fact in mind, suppose a volume of air to be "saturated." Now suppose its temperature to be suddenly lowered several degrees. It must be very plain that, at its lowered temperature, the air cannot hold all the moisture which is in it. The *extra amount*, which cannot now be held, can do nothing but change again to its liquid state, and fall out of the air in little drops. We say that the extra vapor is *condensed*, and we call the process *condensation*.

The *rain* gives us a good example of these processes. Warm air near the earth is constantly taking in water vapor by evaporation from the surface of rivers, ponds, and the ocean. This warm air sometimes rises high, and there meets a current of cold air. In this way *it is cooled so much that some of the vapor condenses*, as we have seen, in little drops. A great many of these tiny drops together form a *cloud;* there the drops stay till they get large enough to be heavy, and then they fall as rain.

A *fog* is formed just like a cloud, but it is very near the earth. *Dew* is formed when the vapor condenses on grass, trees, etc. *Snow* is vapor condensed in the

same way as rain, only that it is so cold as to make the vapor form *crystals* instead of drops. Water forms on a pitcher of ice water in summer, because the cold pitcher condenses moisture from the warm air. In the same way our breath forms moisture on a cold window pane, or in cold air on a frosty morning.

125. Distillation. — This is another important use of evaporation and condensation. It is used in separating liquids from mixtures, in purifying liquids, and in other ways.

In Fig. 106, *c* is a "condenser"; a coiled tube, *e*, runs through it, opening out at *n*. The tube is kept cool by cold water which is always running in at *p* and out at *o*,

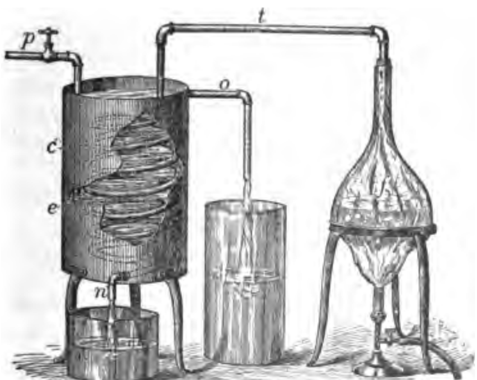

FIG. 106

filling the condenser all around the tube. The liquid to be distilled is boiled in the flask *f*; the vapor goes through the tube *t* to the coiled tube *e*. *This tube being kept cold, the vapor passing through it is condensed* and

runs out at *n* as a liquid. Of course when the liquid is boiled, none of the impurities in it are changed to steam or vapor, and so the condensed liquid which runs out at *n* will be pure. This explains why distillation is of value. Many large steamers carry condensers, so that they can distill the salt water of the ocean and use it.

QUESTIONS

1. What is the melting point? the solidifying point? How do the two compare in any single substance? What is the boiling point?

2. How is a body liquefied? solidified? vaporized?

3. How are these temperatures (boiling point, etc.) affected by pressure? Is the water in a locomotive boiler (under 180 pounds pressure) more or less than 100° C.? State use of vacuum pans.

4. Explain what is meant by evaporation.

5. Does evaporation require a temperature of 100° C.? Does evaporation require any heat? What is evaporated water called?

6. What three conditions of air greatly assist evaporation?

7. Show why motion (of the air or of the moist surface) helps evaporation.

8. When is air said to be saturated? Upon what does the saturation point of any volume of air depend?

9. Under what conditions is the vapor in the air condensed? Explain the formation of rain; of dew; of snow; of fog. How is frost formed on a window pane? Why do summer showers bring a heavy fall of rain?

10. Describe the process of distillation. Of what use is it?

SECTION VII

SOME CHEMICAL EFFECTS OF HEAT

126. Chemical Changes. — *Chemistry* is that branch of science which treats of the *structure* or *composition* of matter. The distinction between the domain of Physics and that of Chemistry is not sharply drawn; but in general we may say that Chemistry covers everything connected with the *formation* of substances, and Physics treats of all behavior of matter which does not change its formation.

A word may make this clearer. Matter is composed of *elements*. An element is a simple, pure substance; it cannot be made by man, nor can it be destroyed. Most metals (iron, silver, copper, mercury) are elements; also such common substances as carbon, sulphur, oxygen, and hydrogen are elements. These substances are rarely found pure, however; they usually occur united with other elements. Now, two or more elements may unite to form a single substance *which may be quite unlike either of the elements;* such a substance would be called a *compound*. Chemistry may then be said to treat of elements and the formation of compounds.

All changes which affect the formation of compounds are called *chemical changes*.

127. Composition and Decomposition. — In general, chemical changes may be divided into two classes,— composition and decomposition.

When two or more substances unite to form another, different one, the process is called *composition*. When

a compound substance is broken up into its elements, the process is called *decomposition.*

128. Effect of Heat upon Chemical Change. — Heat plays a very important part in both sorts of chemical action. Many substances which are so adapted to each other as to be able to unite, may lie side by side for a long time unless heat be applied; then they quickly unite. Gunpowder, for example, contains several substances which may unite with each other; not till heat is applied, however, does this union really take place, and then the new gases just made exert great force in expanding.

The explanation of such phenomena lies in the fact that *before certain substances can unite chemically, they must be heated to a certain temperature.* Hence the application of heat is necessary to many processes of composition.

Similarly, the process of decomposition frequently requires a high temperature. Substances which decompose very slowly (if at all) at ordinary temperatures, easily break up in an ordinary fire; others require higher degrees of heat; and many substances which have resisted all previous attempts at decomposition are now easily broken up by the intense heat of the electric furnace.

129. Combustion. — *Oxygen*, one of the gases in the air, is a very active element. At ordinary temperatures it unites slowly with many substances, forming a class of compounds known as *oxides* (*e.g.* iron rust). At higher temperatures it unites with a vast number of substances, usually giving off *light and heat.*

Combustion (or burning), as the word is generally used, means simply *the chemical union of a substance with oxygen.* To bring about this union, it is only necessary to heat the substance (in air) to the required temperature. As soon as the substance begins to burn at any part, the heat set free by its burning warms other parts to the necessary degree, and so the combustion keeps itself going.

The temperature to which a substance must be heated before it will unite with oxygen (burn) is called its *kindling point.* Of course this varies widely in different substances. Matches are tipped with a substance (usually phosphorus) which has a very low kindling point; hence the heat of friction in striking a match is enough to kindle it.

130. Fuels. — Substances which burn at a low temperature are called *inflammable,* as oils, alcohol, kerosene. Many substances will burn, but at a higher temperature; they may be called *combustible.* Those which do not burn at all are said to be *incombustible;* but many such substances might be made to burn at very high degrees of heat in an atmosphere of pure oxygen.

Fire. The word *fire* is used very loosely and often wrongly in place of *heat.* It may of course be applied to fuel in a state of combustion. *Flame* consists of particles of gas or solid matter in a highly heated state. *Smoke* represents solid particles which have not been heated enough to glow. *Ash* consists largely of mineral matter. Much of the consumed fuel goes away in the form of *gas.*

Combustion may be stopped by covering the fuel with some incombustible substance (*e.g.* water) which shuts out the air.

QUESTIONS

1. Of what does Chemistry treat? What is an element? a compound? What is meant by chemical change?
2. Name two general sorts of chemical changes. Define each.
3. What part is played by heat in these changes?
4. Define combustion. Explain exactly how it is accomplished.
5. What is the kindling point? Name substances whose kindling point is high; low. Explain how matches work.
6. Explain how water serves to put out a fire.
7. Why would a lamp be extinguished by blowing downward into the chimney?

SECTION VIII

ARTIFICIAL COLD

131. How all Bodies are cooled. — Earlier in our study we learned that cold is simply the negative condition of heat; that heat means rapid motion of the molecules, and cold means slower molecular movement; also that as cold is simply the absence of heat, we can cool any body, not by putting "cold" into it, but *by taking heat out of it.* The natural and most common way to do this is to place the body near some cooler one which will absorb some of the heat contained in it. Food in a refrigerator is cooled, not by the cold getting into it but by losing some of its heat into the cooler air surrounding it.

Ordinary low temperatures may be produced in this way; but by studying the laws of nature, man has been

able to make use of some of them in the production of much lower degrees of cold. These methods, while just as truly a result of natural law, are said to be *artificial* ways of cooling, to distinguish them from the common method described above.

132. Cold by Melting. — A body is said to be *melted* when it is changed from a solid to a liquid state by the addition of heat. A body is *dissolved*, or put in *solution*, when it is changed from a solid to a liquid by the action of some other liquid upon it. It is not new to us to say that substances may be changed from a solid to a liquid condition by being heated; but it is just as true to say in addition that *when, by any means, the state of a body is changed from a solid to a liquid, heat must be taken on by the body.* That is, if we can by any artificial means melt or dissolve a solid body, heat must be supplied to it during the change. Moreover, if the change takes place very rapidly, a large quantity of heat must be taken into the body from its surroundings; and thus it becomes a cooling agent.

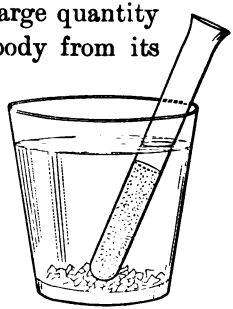

Fig. 107

It is for this reason that a mixture of ice and salt (as used in freezing cream) is so much colder than ice alone. The salt causes the ice to melt very rapidly, and in melting so fast it takes heat out of any body near it.

Certain *salts* have the property of being very quickly dissolved in water. Ammonium chloride and ammonium

nitrate are common examples. If a mixture of these salts be put into a glass of water, their rapid solution will produce a low temperature. If the dissolving mass be stirred with a test tube containing water, heat will be taken from that water so fast as to freeze it in the tube (Fig. 107).

133. Cold by Evaporation. — What has been said of changes from a solid to a liquid state is true also of changes from a liquid to a gas. Such a change may be produced by heating the substance; *but if the change be brought about by any artificial means, heat is necessary and the body will absorb it from the nearest source.*

Pour a bit of alcohol on the hand and let it evaporate. It feels cool. This is because the liquid, upon changing to a gaseous state, takes heat out of the hand — the nearest warm body. Blow upon it and the spot seems cooler yet. Evaporation is hastened by the blowing, and thus more heat is required.

The same thing might be done with ether, naphtha, chloroform, or any of the volatile liquids. In the summer time we perspire more freely than in winter. If a current of air strikes us while we are perspiring, even though the air be warm, it feels cool and refreshing. This is because the rapid evaporation of the perspiration takes some of the heat out of the skin beneath. In this way nature has provided for the cooling of the body when it is dangerously warm.

This principle of cold by evaporation or vaporization is used by man in several ways to produce cold artificially. One or two examples may serve to give an idea of the methods.

134. Artificial Ice. — In warm countries where it is never cold enough to freeze the water in ponds, all the ice they ever used had formerly to be sent there from colder countries. Of late years, however, men have devised methods by which ice may be made very cheaply even in the warmest places. In fact, these methods offer so many advantages over the common supply, that it is

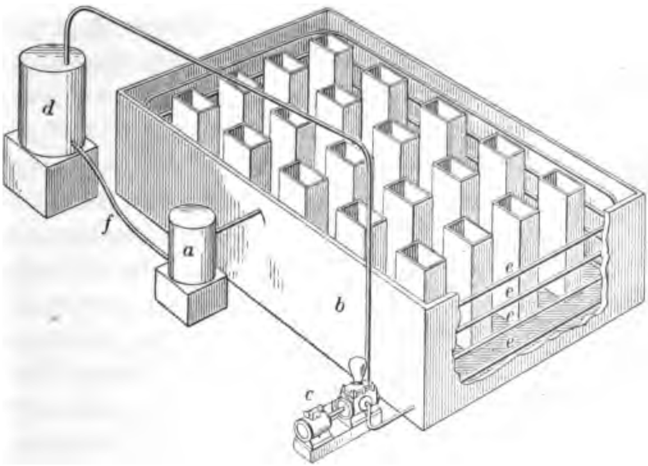

FIG. 108

not at all new in all our northern cities to see great quantities of the so-called artificial ice.

Several substances may be used to produce the result; but as the principle is much the same in all cases, we may consider particularly one of the earliest, — the *ammonia* method. This depends upon the fact that pure ammonia, which is a gas, may be condensed into a liquid form by great pressure; and *as soon as the*

pressure is removed the liquid quickly changes into a gas again, the rapid change requiring much heat.

Fig. 108 may serve to show how this principle is applied. In the figure, *a* is a strong cylinder in which is a quantity of liquid ammonia; *b* is a large tank containing brine (strong salt water), the walls of which are made so as to be non-conductors of heat. In the tank are several rectangular boxes, made of some good conductor, which contain the water to be frozen. A pipe, *e*, leads from the cylinder *a* and makes several turns about the inside of the tank. All parts of the pipe which are inside of *b* are surrounded by the brine, and outside the tank it runs but a short distance to a steam pump, *c*.

Now the boxes being filled with water, and the spaces around them being full of brine, the liquid ammonia in *a* is allowed to expand into the pipes *e*. In a moment these pipes become filled with a half-liquid mass which (because the pressure is removed) is trying to expand into a gaseous state. Of course *this rapid change from a liquid to a gas takes a great deal of heat;* and as the pipes in which the change is going on are surrounded by brine, the required heat is taken out of this. Thus the brine becomes very cold, for salt water will stand a lower temperature (28° F.) than fresh water before freezing; and the water in the boxes, being surrounded by this salt water which is colder than ice, gives up its heat to the brine and freezes.

The pump *c* hastens the evaporation by pumping the ammonia gas out of the pipes and so keeping the pressure low. This gas is forced into another cylinder, *d*, under pressure, and is condensed to a liquid form again.

From *d* it is allowed to run back to *a* from time to time. In this way the same ammonia may be used over and over with hardly any loss.

135. Liquefied Air. — This affords another illustration of artificial cold, for liquid air is simply air at a very low temperature; and, strange as it may seem, the air itself is used as the cooling agent. We cannot study the process in detail at the present time, but the figure may serve perhaps to give us an idea of the principle upon which some of the methods are based.

Into the cylinder *e* (Fig. 109) a volume of air is forced, under the enormous pressure of twenty-five hundred pounds to the square inch. This air is of course very much condensed; and as all the heat of a great volume of air is crowded into a small space, the temperature of the condensed mass must be very high indeed. First, then, the air is led by a tube through a tank of cold water, *t*, where it is cooled to about 10° C. From here the *cooled condensed mass* is conducted to three parallel tubes, *a*, *b*, and *c*. These tubes are inclosed in a cylinder, the walls of which are packed with some non-conducting substance. The cylinder is open at the top, and is pierced at the bottom by the middle tube *c*. All along

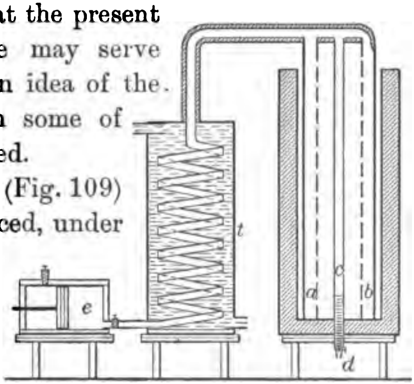

FIG. 109

the sides of *a* and *b*, facing *c*, are very small holes which may be opened or closed at will.

Now, suppose the three tubes to be full of the cool condensed air; the holes in *a* and *b* are opened, so that tiny streams of condensed gas rush out upon the tube *c*. As the imprisoned gas escapes, of course it is relieved of the enormous pressure upon it, and thus it *expands* extremely. *But this tremendous expansion of condensed gas demands a very great amount of heat.* The cylinder walls being non-conductors, however, the supply of heat must come from the condensed air in tube *c*. Thus the expanded air escapes at the top of the cylinder, while the condensed air in *c* continues to part with the little heat remaining in it, till its temperature is so low that it is reduced to a liquid state. This liquid may be drawn off at *d*.

Liquid air, being so cold, tends to vaporize quickly. For this reason it is dangerous to confine it; and while it may have a certain commercial value, the difficulty of handling and carrying it is so great that so far little use is made of it, except by way of experiment.

Once again, in connection with this and with the making of ice, let us note that we produce cold simply by finding a way to get heat out of a body.

136. Absolute Cold. — Earlier in our study we learned that 273° below zero, Centigrade, was considered as absolute cold. This conclusion is based upon facts discovered by a French physicist, and called the *Law of Charles*.

Under constant pressure, the volume of a given mass of a gas increases or decreases in proportion to the rise or fall of its temperature.

The *rate* of change for any gas is $\frac{1}{273}$ *of its volume at 0° C.* for each degree of change in temperature. At this rate a gas cooled to −273° C. would lose $\frac{273}{273}$ of its volume; that is, it would have no volume whatever, and we may suppose this to be because it would have *no molecular action.* In other words, at −273° there would be no heat whatever in a gas. For this reason 273° C. below zero is assumed to be *absolute cold.* The nearest approach to this has been a temperature of about 250° C. below.

QUESTIONS

1. What is meant by artificial cold?
2. In what two ways may solids be changed to liquids?
3. Explain how melting is a cooling process.
4. Show how dissolving one substance may be used to freeze another. What substances are sometimes so used?
5. Ice melts faster if mixed with salt. Show how a mixture of ice and salt is a better cooling agent than ice alone.
6. Explain how evaporation is a cooling process.
7. Why are we in more danger of taking cold when we are overheated?
8. How is the evaporation method used in making artificial ice? Explain the process. Why is ammonia used? Why is salt water used around the boxes? Explain how the ammonia may be used over and over.
9. What principle is employed in making liquid air? Why is the condensed air so very hot? Why, after being cooled, does it take in heat on expanding?
10. What is meant by absolute cold? What is the estimated temperature, in Centigrade degrees, of absolute cold? How is this point determined?

SECTION IX

TRANSFORMATION OF ENERGY

137. Heat is a Form of Energy. — We have learned that heat in a body is simply the result of *molecular motion;* that is, the molecules of which the body is made are set in motion, and that gives rise to heat in the body. Therefore we see that the heat of any substance depends upon the *energy* of the moving molecules; the more energy the molecules have, the warmer is the substance. So we may say that heat is *molecular energy*.

138. All Energy related. — Heat is only one kind of energy; we know by experience that there are other kinds. There is muscular energy, by which we are able to move and cause motion; chemical energy, which causes burning, explosions, and other phenomena; electrical energy, which we shall study later, and many others. Scientists have discovered a close relation between the various kinds.

All forms of energy are so related that one kind may be changed into any other kind of energy. For example, if you rub your sleeve rapidly, you use up muscular energy; that energy is not lost, however, but is simply *changed* into another form, — heat. If you notice, both the hand and the sleeve become warm as you rub.

Another example: The sun's *heat* and *chemical energy* act upon a small plant to make it build up fiber and grow into a large tree. This energy is stored in the wood. Later the wood is burned and gives off energy

in the form of heat. The heat turns water to steam; the steam, applied to an engine, causes motion, and is changed to *mechanical energy*. In each case there is only a change in the kind of energy.

139. No Energy can be lost.—In the last example we traced energy from the sun to mechanical work. But the energy is *not destroyed* there. If we chose, we could go on tracing it: the mechanical energy would be changed to heat, perhaps, as the machines heated their bearings; the heat would go into the air and perhaps do work of evaporation, and so on.

Similarly, any form of energy might be followed through many different changes, each giving it a new form but not destroying it. This fact forms one of the very important principles in Physics; it is known as the principle of the *Conservation of Energy*.

Whenever one kind of energy is changed into another kind, the amount of the second is exactly equivalent to the amount of the first.

140. Latent Heat.—We are accustomed to think that when heat is put into a substance, the energy shows itself in *increased molecular activity*, which of course means a *rise in temperature*. A simple experiment will show, however, that this effect is not always produced. We know that the temperature of ice is 32° F.; to melt a piece of ice requires the use of heat for some time, during which a great deal of heat is taken on by the substance. But if the temperature of the melted ice (*i.e.* the ice water) be measured, it is found to be only 32°.

Clearly, a large amount of heat has gone into the ice, which has produced no rise in temperature.

From this it would seem, at first thought, as if here were a case where energy has disappeared, leaving no other form of energy in its place. It was because of this seeming disappearance that physicists gave the name *latent* (*i.e.* hidden) to *the heat used up in melting a solid or vaporizing a liquid.*

It is now understood that this energy is not lost, but is in some way made to do *interior work upon the molecules;* also the fact has been proved that the heat put into ice to melt it, is *given back* again by the water upon freezing. Water does not freeze just as soon as the temperature falls to 32°, but time is required for it to give up the latent heat which it must lose before solidifying. Farmers sometimes protect their vegetables from freezing by placing pails of water in the cellars with them. The water, in freezing, gives out enough heat to keep the temperature above the low degree at which the vegetables would freeze.

141. Transformation of Energy.—If energy cannot be lost, it is just as true that energy cannot be created. Even the energy of our bodies, which may at first thought seem to be made in our muscles, may be traced back to the food and air we consume; and the food in its turn contains the energy supplied by the sun's rays or by the water from the earth. So we shall find not only that energy *may* be changed from one sort to another, but that if we want any particular sort we *must* get it by changing some other. In other words, *whenever*

man seems to produce some form of energy, he does so simply by changing some other form; even then he cannot actually perform the *change* — man can only supply the conditions, and nature in some unknown way does the work. All such changes of energy from one sort to another are called *transformations* of energy.

QUESTIONS

1. What sort of energy may heat be called? Upon what does the degree of heat in a body depend?
2. What sort of relation exists between different forms of energy? Name some different forms of energy.
3. Can energy be destroyed? What can happen to energy?
4. Can energy be created? How is any particular form of energy obtained? Cite some familiar example of this.
5. State the principle of the Conservation of Energy.
6. What may be the effect of heat energy upon any body? What is meant by latent heat? Is this energy lost? Suppose a quart of water be heated to 212° F. and the supply of heat then removed; will all the water turn at once to steam? Why? Will water at once freeze if cooled to 32° F.?
7. What is meant by transformation of energy?

SECTION X

MECHANICAL USES OF HEAT ENERGY

142. Relation of Heat to Mechanical Work. — The amount of work which a given amount of heat can perform is of course equivalent to the amount of heat obtained from the same amount of work. The relation of heat to mechanical work was first established by Dr. Joule. He fitted a paddle wheel into a box so

that it might be turned by the falling of a known weight a given distance. A certain quantity of water was put in the box, and its temperature taken before and after the weight fell. The moving paddle heated the water. Thus it was easily determined how many calories of heat could be produced by the mechanical energy of a known weight falling a given distance. Careful repetitions of this experiment have given us the following *Mechanical Equivalent of Heat:*

1 calorie of heat ≎ 427 kilogram-meters of work.

That is, one calorie of heat is equivalent to the energy spent in raising 427 kilograms of matter to a height of one meter.

143. Devices for using the Energy of Heat. — For many centuries men have known something of the *expansive power* of heated gases, and even before the beginning of the Christian era we find that this power was used in a few instances and made to do work. At present there are numerous engines of different types which depend upon this sort of energy; in fact, the number has grown so rapidly within a very few years that we have difficulty in keeping posted. The principle in many cases is quite similar, and a brief study of a few types may furnish a good idea of the way in which man makes use of the energy supplied by heat.

144. Steam Engine. — Perhaps most important of all is the steam engine, devised and improved upon by James Watt about the year 1765. It makes use of the *expansive force of steam,* which is of course simply water in the state of a highly heated gas.

The steam is generated in a *boiler* and conducted to a *cylinder*, where it is made to strike first one side and then the other of a *piston*. Thus the piston is driven to and fro, its motion being transmitted by a *crank* or *eccentric* to a *fly wheel* or a *shaft*.

Fig. 110 may serve to explain this motion and how it is brought about. In the figure, *t* is a pipe which conducts the steam, under high pressure, from the boiler to a box, *d*, called the *steam chest*. From the steam chest,

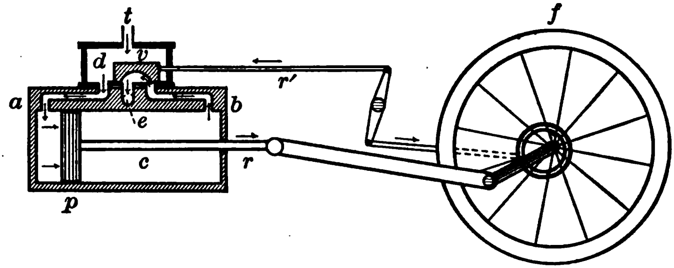

FIG. 110

two pipes lead to the cylinder *c*, opening into it near the ends *a* and *b*. In the cylinder the piston *p* moves back and forth, and this motion is carried by rods and a crank to the fly wheel *f*. Attached to the shaft of the wheel by another *eccentric* is a rod which moves a *slide valve*, *v*, in the steam chest. Notice that the arrangement of cranks on the shaft is such that, as the *piston rod r* moves in one direction the *valve rod r′* moves in the opposite direction. The opening *e* leads to the *exhaust pipe*, — that is, the outlet for the steam which has been used. Through this pipe the steam is conducted to the air or to a condenser.

Trace the action of the engine. Steam from the boiler passes through *t*, *d*, and *a* (see Fig. 110), and striking the piston *p*, moves it in the direction indicated by the arrows. Going toward *b*, the piston drives out the exhaust steam which was used in the previous stroke. The motion of *p* also sets the shaft and wheel in motion. This causes the valve rod *r'* to move as shown by the arrow; the slide valve also moves with it, until, as *p* gets to the end *b*, the valve is at the other end of *d*. In this position (Fig. 111) fresh steam goes to the end *b*, forces the piston toward *a*, and drives out the expanded steam through *e*, as the figure shows.

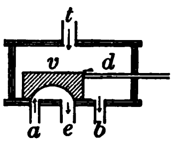

FIG. 111

145. Steam Locomotives. — The locomotive engine used on railroads (Plate III) is a later invention than the engine of Watt. Owing to the nature of its work, the locomotive consumes unusually large quantities of steam. In order to generate the steam rapidly enough, a *large heating surface* is necessary; also a *powerful draught* for the fires.

The draught is produced in this way. From the fire box through the boiler and smokestack is one continuous passage. The exhaust steam from the engine is forced out through the smokestack; as the steam rushes out it leaves a *partial vacuum* in the smokestack, and a strong current of air from below the fire box rushes through the fire and boiler to fill this vacuum. This explains the cloud of steam and smoke which pours out when an engine is "puffing" heavily. As the

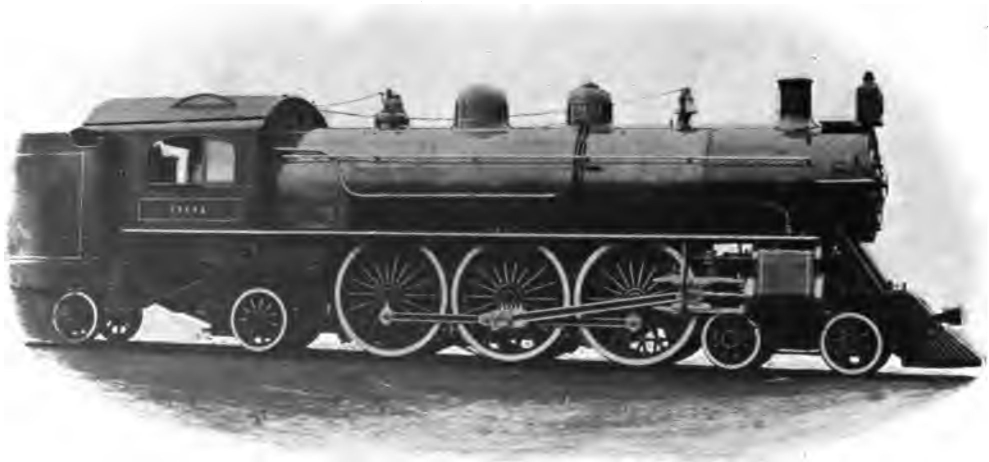

Plate III. A Steam Locomotive

locomotive has a cylinder on each side and each cylinder has two exhausts, it follows that the engine puffs four times to each turn of the wheels.

146. Compound Engines. — *Compound* and *triple-expansion* engines use the steam two and three times; that is, the exhaust from one cylinder leads to another cylinder, where it presses upon a larger piston before being sent out into the air. Both (or all three) pistons are connected with the same shaft. Such engines are designed to get the greatest possible amount of work out of the steam.

All steam engines are very wasteful. The best of them do not convert into motion one fifth of the energy in the coal they consume.

147. The Steam Turbine. — The to-and-fro motion of the piston causes a great jarring upon the parts in an ordinary steam engine. For this reason there must be a limit to the speed at which such an engine may be run.

Recently the *turbine* engine has attracted considerable attention. This type of engine consists of several blades attached to a shaft (somewhat as in a common water wheel); the whole is turned by *jets of steam* which escape from small openings and play upon the blades. Owing to the *rotary* motion of this engine there is little jar; as a result, a very high speed may be obtained. The turbine engine has been tried in some of the fast naval vessels with remarkable success.

148. The Hot-Air Engine. — This device uses the *expansive force of heated air* to do work of a light nature.

The diagram (Fig. 112) is not a picture of the inside appearance of such engines, but it may help us to understand how they work. The piston *p* moves in a cylinder, *c*, and its motion is made to turn a fly wheel, *f*. *d* is a hollow cylinder, connected with the shaft *t* so as to move up and down loosely in the *air chamber ab*. Air is heated by a fire under the end *b*; but as *d* drops down, it displaces this warm air, which moves up to *a*. This end being surrounded by cold water in the *jacket e*, the air is quickly cooled here.

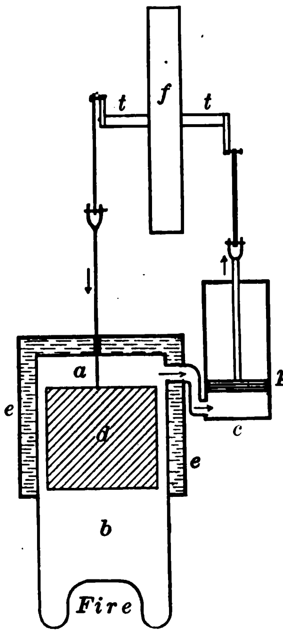

FIG. 112

To start the engine, *f* is turned by hand; *d* rises to *a*, forcing the air down to *b*; here it is at once heated very highly, so that it expands, filling *ab* and causing *pressure* on the end of *p* also. Thus *p* is forced upward, turning *t* and *f*. But as *t* is turned, by an upstroke of *p*, *d* will be dropped down to *b*; this forces the warm air up to *a*, where it *cools* and *contracts* at once. The momentum of the fly wheel *f* is now great enough to force *p* back to the bottom of *c*, since the contraction of air in *a* greatly reduces the pressure. But as *p* is lowered, *d* once more rises and drives the cool air from *a* to *b*; here it is once more heated, and the operation repeated.

Note that p does the work, while d simply shifts the air. The same air is used over and over, it needing but an instant to become heated at b and cooled at a.

149. Gasoline Engines. — With the increasing number of small power boats, motor carriages, and the like, this type of engine is much in use. Power is furnished by the *explosion of a mixture of air and gasoline vapor* above the piston in a cylinder. Of these engines the most common is known as the *four-cycle* type.

By means of an electric spark the gas is exploded, the force of explosion driving the piston on its downstroke; on the return stroke the exploded gas is driven out of the cylinder. Another downstroke draws in a fresh supply of gas, which is compressed by the return stroke. This compressed gas is now exploded, driving the piston down for another cycle of four strokes.

From this it will be seen that the motion must be jerky. This is somewhat reduced by a *heavy fly wheel*, which also serves by its momentum to keep the engine going through its three unaided strokes.

150. The Naphtha Engine. — This engine uses the *expansive force of naphtha gas*, without explosion. By burning a mixture of air and naphtha at the base of a coiled pipe, naphtha inside the pipe is heated to a gas. This heated gas is allowed to *expand* into three cylinders, where it exerts pressure upon three pistons. The exhaust (being pure naphtha vapor) passes through a pipe surrounded by cold water, where it is condensed to a liquid and may be used again.

The advantage of this engine is that the pressure is carried to the shaft at three different angles (Fig. 113), so that instead of one pressure to two turns of the shaft (as in the four-cycle gasoline engine), there are three pressures to one turn of the shaft.

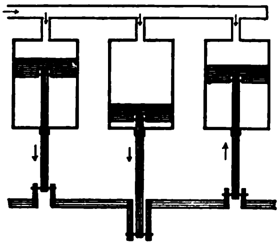

FIG. 113

QUESTIONS

1. State the unit of measure for quantity of heat. How much is one calorie?

2. What is meant by the mechanical equivalent of heat? State the mechanical equivalent of heat. How was this determined?

3. By means of what state of matter is heat usually made to do work? What property of gases makes them very powerful for this purpose?

4. Who invented and improved the common steam engine?

5. From what does a steam engine get its energy?

6. Name the more important parts of a steam engine.

7. Make a diagram and explain the action of the common steam engine.

8. What is the special feature of the locomotive? Why does a locomotive rarely stop on a "dead center"?

9. How does a compound engine get more work out of steam?

10. Explain the action of the steam turbine. What is its advantage over the piston type of engine?

11. How is hot air applied to run an engine? For what are hot-air engines used?

12. Explain the action of the gasoline engine. What is meant by "four-cycle" engine? What keeps such an engine running during the odd strokes?

13. What furnishes power to run the naphtha engine? State the advantage of the naphtha over the gasoline engine. Is the fly wheel needed in the naphtha engine?

CHAPTER V

SOUND

SECTION I

WAVE MOTION

151. Waves. — Two ways of transmitting motion are known to man: the first, *a bodily movement of an object as a whole,* — as the motion of a thrown ball, a flowing liquid, or the convectional movement in a gas or liquid; second, *motion transmitted by the particles of a body,* — as the ripples on the surface of a vessel of water which is shaken, or the conduction of heat (molecular motion) through a body. Any movement transmitted through a body from particle to particle is called a *wave.*

Examples of such *wave motion* are very familiar. We have seen the smooth surface of a pond thrown into ripples by a pebble; a blow struck on an iron bar may be felt at the other end; the slamming of a door or the heavy notes of a pipe organ may send a jar through an entire building. The firing of a blast or a heavy cannon may rattle the windows in a house some miles away. The explosion of a volcano (Krakatoa) in 1883 caused a distinct disturbance of air, which could be measured by barometer pressure, to pass three times around the earth; and a tidal wave traveled entirely across the

Pacific Ocean. These few examples furnish an idea of what is meant by wave motion. Its importance is great, and a knowledge of it is quite necessary to an understanding of sound and light.

152. Vibration. — *The motion of any particle affected by a wave is called a vibratory motion or vibration.*

It must be understood at once that by such motion the position of the particle is not *permanently* changed. This is just the difference between the wave motion and the other or bodily motion. It is true that as a *result* of wave motion the position of a particle *may* be changed

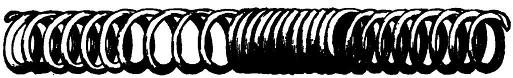

FIG. 114

forever, but in just so far as this change is produced we must consider bodily movement to occur along with the wave. *Each particle in a wave is supposed to receive its motion from some other particle, to move itself, and, after giving this motion to another particle, to come to rest at its former position.*

153. Direction of Vibration. — When the direction of motion of the vibrating particle is the same as that of the wave itself, the vibration is called *longitudinal.* The vibrations of a spiral spring, as shown in Fig. 114, are longitudinal.

Transverse vibration is shown in Fig. 115. A cord or rope, fastened at one end, is set in vibration by a movement of the hand. Any vibrating particle does not move

forward or backward, but at right angles to the length of the cord, as shown by *ab*. This motion, in which the vibrating particle moves at right angles to the direction of the wave, is transverse vibration.

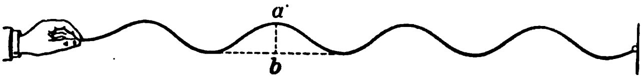

FIG. 115

Torsional vibration is perhaps less common. The motion is similar to the unwinding of a curtain cord which has been tightly twisted.

154. Definitions. — In Fig. 116 let the dotted line represent a piece of cord, and the continuous line the same cord in a state of vibration.

The *period* of a wave would be the time it took any particle (*a*, for example) to go through one entire vibration and return to the position it had at the start, — from *a* to *b*, then down to *c*, and up to *a* once more.

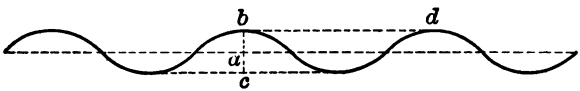

FIG. 116

The *length* of a wave (or *wave length*) is the distance from any vibrating particle to the next particle which is in the same state of vibration, as *bd*.

The *amplitude* of vibration is the distance between the extreme positions which the vibrating particle reaches, as *bc*.

155. Stationary Vibrations. — If the cord be fastened at one end, it may be made to vibrate in such a way that the motion shall be sent back at *c* (Fig. 117), causing *stationary* vibrations; that is, at any point (as *a*, *b*, or *d*) the particle would move to and fro without going to the full limit of vibration, as it would if the wave were simple. For instance, the outgoing wave, *a* to *c*, would tend to move *d* to *d′*; but before it gets there the return wave, *c* to *a*, stops it at *e*, giving the particle an

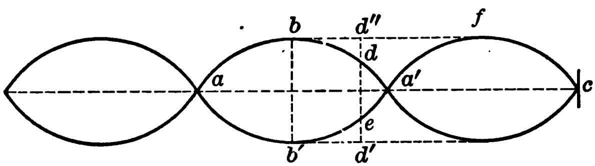

FIG. 117

impulse toward d″; at *d*, however, it is again stopped by the next wave from *a*, and so it is kept going between *d* and *e*.

A particle in the position *a* is kept there by the opposing waves, because both impulses arrive at that point together; such a point is called a *node*. Since the opposing impulses arrive at a node together, it is clear that there are points just halfway between the nodes at which the impulses are just half a period apart; that is, when *ac* is at *a*, *ca* is at *c*. So when *ac* has arrived at *b*, *ca* has reached *f*; *ac* and *ca* then reach *a′* together, and *ca* arrives at *b′* just half a period later than *ac* reached *b*. Thus a particle, *b*, can move to the full extent of the amplitude of either wave, *ac* or *ca*. This point in a stationary wave is called the *antinode*.

156. Vibration Rate. — *The rate or frequency of vibration refers to the number of waves which pass any given point in a given length of time.* It is usually expressed by a certain number of *vibrations per second.* Rate is sometimes called *vibration number.*

The subject of wave motion is of importance at this time, because of its relation to the subjects of *sound* and *light.* It will be of advantage, besides remembering the definitions, to get very clearly in mind what is meant by a "wave," and how wave motion is transmitted through any body from particle to particle.

QUESTIONS

1. What two ways of transmitting motion? Illustrate each.
2. What is a wave? Describe wave motion.
3. Explain the meaning of vibration, or vibratory motion.
4. What is longitudinal vibration? transverse? torsional?
5. What is the period of a vibration? amplitude? wave length?
6. What are stationary vibrations? How are they formed? Define the nodes; antinodes.
7. What is meant by rate of vibration, or vibration number?

SECTION II

WHAT SOUND IS

157. Three Factors of Sound. — Suppose some one across the room strikes a bell; we hear a sound. But what makes the sound? Clearly the bell must have had something to do with it, and if we look at the bell at once we see that it is trembling (*vibrating*) very fast. Is this sound? No, it is only motion; but this motion

caused the sound. A little more thought will show that the ear, as well as the bell, has something to do with the sound; it is with the ear that we "hear" it.

We have seen that the bell caused the sound, and the ear heard; but how did the ear hear? It is easy to guess that something must have gone from the bell to the ear through the air. A little later we shall understand what it was which went through the air; but for the present let us simply give it a name and say that *sound waves* went from the bell to the ear. The air which carries these sound waves is called a *medium.*

From this study, then, we learn that three factors are necessary to sound: first, a cause or *origin;* second, a *medium* to carry the sound waves; third, an *ear* to receive them.

158. Definition.—These three things are all necessary in order that there may be sound. Let us try to understand this. At the bell we have only a trembling *motion;* in the air, nothing but *sound waves* (air set in motion by the motion of the bell); it is not until these sound waves strike upon an ear that there is *sound.*

Sound is the sensation produced by the action of sound waves upon an ear.

159. Sound distinguished from Sound Waves.—Note the importance of the ear as a factor of sound. The thought may seem a bit odd at first, but it is none the less true that without an ear of some sort present to receive the sound waves, there would be no true sound. It is not a *noise* which comes traveling through the air when a distant gun is fired, it is not a *sound* which

disturbs the quiet air when a bell is rung. True enough these things report themselves to an ear as noise or sound; but to a tree or a building, or to a person without the sense of hearing, they seem to be just what they are, — simply *disturbances of the air.*

Nature has provided man and animals with a sense organ by which these disturbances are received; and the report of the ear to the brain is what we call *sound.* It is of course very convenient, and in many cases necessary, that man should have some way of discovering these disturbances; but most of them are far too tiny to be felt or seen, so it is the particular business of the ear to discover them.

It is not uncommon in ordinary use to employ the word *sound,* meaning the disturbance or the sound waves which caused it. For our present study, however, it will be well to use the word in its strict meaning.

QUESTIONS

1. What are the three factors of sound? If no ear were near enough to catch the waves, would there be sound? Could there ever be sound if any one factor were missing?

2. State the meaning of sound waves.

3. Give definition of sound.

4. Carefully show the distinction between the word *sound* as commonly used and its stricter meaning.

SECTION III

THE CAUSE OF SOUND

160. Its Origin.—In the sound just described, the striking of the bell was the *origin* (first cause) of the sound; we found that when struck, the bell *vibrated* or trembled. In the same way, if we strike a drumhead, a thin tumbler, a piano or violin string, or blow into a horn, we can see or feel each *vibrate* as it gives out its sound.

Sound has its origin in a vibrating body.

In all cases it is not so easy to discover the vibrations, though they are always made. If we clap our hands, the air is set in rapid motion; and it is partly the vibration of the air, partly that of our hands, which causes the noise. If a gun is fired, sound is caused by vibration of the air, which is set in motion by the explosion. When one talks, sound waves are made by vibration of the vocal cords in the throat. So with any sound, if we can discover its *origin*, we shall find that it started in some body which was vibrating

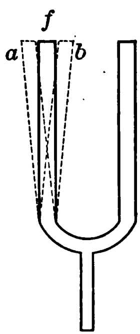

FIG. 118

161. Sound Waves. — The next question is, How do these vibrations cause *sound waves* in a medium? Suppose the prong *f* of the tuning fork (Fig. 118) to vibrate, flying back and forth between the positions shown by dotted lines *a* and *b*. As *f* moves towards *a*, the air in front of it is *condensed*, that is, crowded into a denser mass; as *f* swings back towards *b*, the air which it leaves on the side

a becomes *rarefied* (thinner). Now, as it vibrates quickly back and forth, these *condensations* and *rarefactions* follow each other in quick succession. *The air, being an elastic medium, transmits these impulses very rapidly, and while in the medium they form the sound waves.*

FIG. 119

162. How Sound Waves travel through a Medium.— We have seen ripples start and spread out in all directions from a pebble dropped in still water. The sound waves travel in much the same way, spreading out in every direction from their origin. Fig. 119 shows this, the dark bands, *A*, being condensations, and the light ones, *B*, rarefactions.

The whole air does not move forward all the time, any more than does the water of a wave move along

with the wave. But as a condensation moves forward, *each particle of air hits the one next to it and pushes it on;* as soon, however, as the particle has moved a little way, *it returns to its former position again,* and this causes the rarefaction. This may be shown by a coiled spring, as in Fig. 120. If we stretch the spring just a little, and pull the first few coils back toward *a* so that they are crowded together as in the section *d*, we form a condensation. Let go, and the condensation will travel

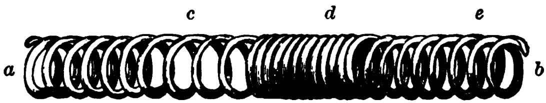

FIG. 120

quickly along the spring toward *b*. A rarefaction, *c*, will follow this condensation, and then each coil will return to the position it first had, as in *e*. It is in this way that sound waves travel through a medium.

163. The Ear. — When sound waves reach the ear, they hit upon a sort of drumhead, the *tympanic membrane,* causing it to vibrate. This in turn causes other vibrations inside the ear, and these finally affect some of the many ends of the *auditory nerve.* This nerve goes to the brain. It is the effect of vibrations upon these nerve endings which gives us the sensation of sound. The exact manner in which the auditory nerve receives these impulses does not concern our present study. It may be said, however, that the nerve endings consist of many little rods, each one of which is supposed to respond to a certain wave length.

QUESTIONS

1. In what do all sound waves have their origin?
2. What is meant by a medium? What is a condensation? a rarefaction?
3. Explain how the vibrations of a body cause sound waves in the medium. By virtue of what property does the medium then transmit them?
4. What is the auditory nerve? Of what use is it in sound?

SECTION IV

TRANSMISSION OF SOUND WAVES

164. Different Media. — Most of the sounds that we hear come through the air; and even if the waves have come through some other medium, they must travel a little way through the air to get into the ear. But after all, the air is not a very good medium. If you have ever gone entirely under water while bathing and knocked two stones together, you know that they sound more loudly than they would in air: the water is a better medium. *In general, liquids are better media than gases.*

Perhaps, while waiting for a train sometime, you have heard the sound of it through the rails long before it came through the air. Or you have, perhaps, seen a man far up the track strike it a blow; soon the sound is heard through the rails, and then quite a pause before it comes in the air. *In general, solids are better media than liquids or gases.*

A common toy (Fig. 121) shows this. If a stout string be fastened to the bottoms of two tin boxes, the whole

FIG. 121

may be used as a telephone. The string must be pulled tight; then by talking into one box the vibrations are transmitted to the string, along that to the other box, and so to the ear. In this way two may talk while much farther apart than they could talk through air.

165. Velocity. — The speed with which sound waves travel depends much upon the medium. They will go through water four times faster than through air, and through iron sixteen times faster.

Through air at ordinary temperature, sound waves travel about 1125 feet per second; that is, sound waves would go a mile in about five seconds. This explains why it is that we *see* a blow struck, a gun fired, or a whistle blown, so long before we *hear* the sound. It explains, also, why there is a pause between lightning and thunder; really both occur at the same instant, but it takes sound waves much longer than the light to get to us. If we count the number of seconds between the flash and the noise,

and divide by five, it will tell about how many miles away the lightning is.

The velocity of sound waves depends upon the *elasticity* and the *density* of the medium through which they are passing.

The velocity of sound waves in any gas varies directly with the square root of its elasticity, and inversely as the square root of its density; or, more simply, the more elastic the gas the greater will be the velocity of sound waves, and the denser the gas the less their velocity. Thus, through warm air the waves will pass more rapidly than through cold air, for the warmer air is expanded (*i.e.* not so dense).

At zero on the Centigrade scale the velocity of sound waves in air is 1090 feet per second. For each degree Centigrade that the temperature increases, the velocity will increase by about two feet per second. Thus at 17° C. (an average temperature of air) the velocity would be $1090 + (17 \times 2)$, or 1124 feet per second.

Sound waves will not travel through a vacuum; they must have a medium of some density.

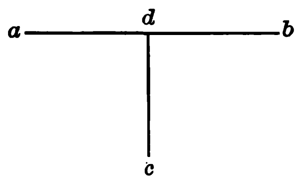

FIG. 122

166. Echoes. — If you throw a ball at a board fence *so as to strike it at right angles*, — as the line *cd* (Fig. 122) meets the line *ab*, — the ball will come straight back to you, as along the line *dc*. But if you hit the fence at any other angle, the ball will bound off from you, as in Fig. 123, where the ball moves along *gh*, hits *ef* at *h*, and goes off along *hl*.

Now in the same way sound waves may strike a building, hill, or bank of woods and be turned back. *If they happen to strike at right angles, they will come back to us and we shall hear an echo.*

The echo will be softer than the first sound, because the waves have gone so far. We can hear echoes only when there are no other loud noises, because the sound waves have lost so much energy in traveling. Notice that sound waves may strike a body and "glance off" from it at any angle; it is only when they strike *at right angles* (Fig. 122) and come straight back to where they started that we hear the echo.

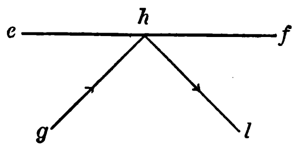

FIG. 123

167. Reverberation. — Sometimes, as in a large empty hall, we hear a confused rumbling sound after we have spoken or shouted. This is due to the sound waves, which strike the walls and bound back and forth between them. It is like a quick succession of echoes, following each other so closely that they make only a confusion of sounds in the ear. Such a thing is called a *reverberation*. We hear it also if we shout into a well, an empty hogshead, a cave, etc.

QUESTIONS

1. How do solids, liquids, and gases compare as media for sound waves? State some common examples to prove this.
2. Why can we see the smoke from a gun some time before the sound is heard? How fast do sound waves travel in air?
3. In how many seconds will sound waves travel a mile?

4. Upon what does the velocity of sound waves depend? State the law for velocity of sound waves in gases.

5. Do sound waves travel faster in warm or cold air? How much increase for every Centigrade degree? Do sound waves travel in a vacuum?

6. How is an echo caused? Why can we not hear any echo except in a certain position? Why do we hear echoes best over a stretch of water or level plain?

7. What are reverberations? Where can they be heard?

SECTION V

LOUDNESS OF SOUND

168. Loudness. — Strictly speaking, loudness means the *intensity of the sensation* made by sound waves in the ear; we must not confuse it with intensity of the sound waves themselves. The loudness of a sound may depend upon several things, — the *intensity of the original vibrations*, the *distance* of the ear from the origin, the *kind of medium* through which the sound waves have come, etc. For the present study, however, the following statement may be useful.

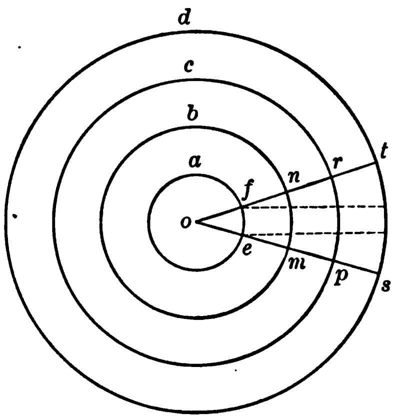

FIG. 124

Other things being equal, the loudness of a sound will vary as the energy of the sound waves that reach the ear.

We know that, as a rule, the farther we go from the origin of a sound the softer it seems to us. Fig. 124 may help to explain this.

In the figure let *o* be the origin of the waves, and let the circles *a*, *b*, *c*, and *d* show the positions of the waves as they spread out at different distances from *o*. Now it is easy to see that the energy of the waves between *e* and *f*, at the distance *a*, will be spread over the space *mn* when they get to the distance *b*. On reaching *c* and *d* the waves will have no greater energy than at *a* and *b*; that is, the energy which at *a* is included between *e* and *f*, is spread over the space *st* at the distance *d*. Thus the energy of the sound waves that an ear would receive at *s* is so much less than the same ear would receive at *e* that the resulting sound must be not nearly so loud.

FIG. 125

169. Ear Trumpets; Speaking Tubes. — It is clear, then, that usually we want as many waves as possible to hit upon the ear. The opening to the ear is only a small hole which would not catch many waves; so the pinna (the outside structure of the ear) is placed around the opening to catch more waves and direct them into the inner ear. Old people who hear with difficulty sometimes put their hands back of the pinna so as to catch more sound waves.

For the same purpose an *ear trumpet* (Fig. 125) is sometimes used. The small end *e* is placed in the ear, while the large opening *b* flares out so as to catch many waves; it then tapers to the end *e* so as to direct them to the ear.

Speaking tubes made of small tin pipe are sometimes used as telephones for short distances. By talking directly into the end of the tube, *all* the sound waves enter it and may be carried a much greater distance than if they were spread about in all directions.

Loudness is of course affected by other factors, but we have perhaps obtained a general idea of what it means from this study.

QUESTIONS

1. Define loudness of sound. How does this differ from intensity of vibration?

2. Upon what may loudness depend?

3. Show how intensity of sound may decrease as the ear is farther removed from the source of the waves.

4. How may we hear more distinctly if we place a hand back of the ear? Explain the use of ear trumpets; of speaking tubes.

5. Why may a distant bell be heard some days and not others? Why do we hear some sounds better in the early morning or late evening?

6. Do sounds seem more distinct when they come from a distance over water or over land? Explain.

SECTION VI

REËNFORCEMENT OF SOUND WAVES

170. Vibrating Bodies may cause Vibration. — Other vibrations than those of the body in which they originated often take part in causing sound waves. Some body which is near to or actually touching the vibrating body, may itself be set moving *by the influence of those vibrations.* As these motions are the result of the original vibrations, they will have just the same rate and give rise to the same sort of waves. Thus the second vibrating body adds its energy to that of the first, so that the energy of the sound waves will be consequently increased.

Of these extra vibrations two different sorts are considered, *forced* and *sympathetic.* The difference between them will be shortly explained.

171. Sound Waves may cause Vibration. — Not only do vibrating bodies produce vibration in others which they touch, but sound waves may themselves cause vibrations in bodies upon which they strike. We can hear sounds made out of doors, even in a room with doors and windows closed. The sound waves striking upon one side of a window pane, for example, cause vibrations in the glass; the moving pane sets up vibrations of the air in the room, and these reach the ear. Of course the waves lose much of their energy in making the solid substance vibrate, and the sound is not nearly as loud as if the window were open.

172. Forced Vibrations. — If a tuning fork or a common silver table fork be struck against some solid body so that its prongs are made to vibrate, a clear tone may be heard if the fork is held *close to the ear.* If, however, the blow be struck and the handle be quickly placed on a board or table (leaving the prongs free, as in Fig. 126), the tone may be clearly heard *some distance away.*

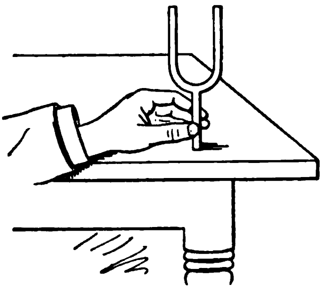

FIG. 126

The reason for this is simple. The vibrations of the prongs are transmitted through the handle to the table, causing the table to vibrate at the same rate as the fork. In this way a much larger body of air is set in motion by the vibrations of the table; and as the rate is the same, the sound waves thus caused are added to those made by the fork itself, and the sound seems louder.

The vibrations of the table in this case would be called *forced vibrations.* The table as a whole would, of course, have its own rate of vibration; but being made to vibrate by actual contact with the fork, it is *forced* to vibrate at the same rate as the fork.

When a body is made to vibrate by another vibrating body, at a rate not its own, it is said to be in a state of forced vibration.

Examples of this are common, and in many cases important. The thin pieces of wood which make up the boxes of violins, guitars, mandolins, and similar musical instruments are thrown into forced vibrations

by the movement of the strings; the head of a banjo acts in the same way. Pianos have a large *sounding-board* back of the strings to increase the "volume" (loudness) of tone. A piano without its sounding-board, or a violin without its box, would be of little use as a source of entertainment to any but the player. A harp, though its strings are long and heavy, gives a very soft, delicate tone, because it has practically no sounding-board.

173. Sympathetic Vibrations.—If we raise the dampers from the strings of a piano and then sing a tone for a moment, the same tone may be heard issuing from the piano. By raising the dampers all the strings are left free to vibrate. As a tone is then sounded from outside the piano, the sound waves strike upon all the wires; but they cause vibration only in the one which has *the same natural rate* as the body originating them.

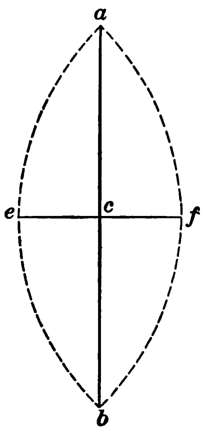

FIG. 127

When a body which has the same rate of vibration as another is made to vibrate by the influence of vibrations in that other, its vibrations are said to be sympathetic.

Fig. 127 may help to make this clear. Suppose a sound wave passing through the air from the direction *f* strikes a string *ab*, having the same rate of vibration as itself. The first *condensation* of air which hits upon *ab* sends it a little way toward *aeb*; then follows a *rarefaction* which allows the string to snap back, past *acb* and on toward *afb*. This latter

position is reached just as the next condensation comes along; so that the string, which would of its own accord snap back once more toward *acb*, is helped by the impulse of the sound wave and carried with it toward *aeb*. Thus every time the string snaps from *f* toward *e*, a condensation comes along at that instant and helps it; every return from *e* toward *f* is likewise helped by the following rarefaction. So, though each impulse of the air may be feeble, *each comes at just the right moment to add its little to the weak vibration already started by those before;* and it takes but a few to arouse a considerable vibration in the string.

A bit of thought shows why no other string will vibrate. If *ab* has a faster rate than the sound wave, it starts to go toward *f* before the condensation has passed, and so it not only lacks the help of the rarefaction but is held back somewhat by the condensation. If its rate is slower than the wave, it starts toward *f* during the rarefaction following the first condensation; but before it gets there, along comes the next condensation and stops it. So it is with any string; whether its rate be slower or faster than that of the sound wave, whatever motion may be started by any feeble impulse is very soon destroyed by a later one which strikes it at the wrong time.

With a similar principle in mind, naval experts design the clumsy, top-heavy warships so that their rate of rolling shall be slower than the slowest ocean waves. As a result, the roll started by one wave will very soon be opposed by another wave, striking at the wrong moment, and its effect destroyed. Should such a vessel get into

a sea where the waves moved at the *same rate* as its own rolling, then each succeeding wave would strike at just the right moment to add its impulse to what motion the ship already had, and after a very few waves it would roll so far as to tip over.

174. Forced and Sympathetic Vibrations compared. — The difference to be noted between the forced and sympathetic vibrations is that forced vibrations have a *different rate* from the natural vibration number of the body, whereas the sympathetic are to be aroused only in a body whose *natural rate is the same* as that of the original vibrating body.

175. Resonance. — This reënforcement of sound waves by other vibrating bodies is quite commonly called *resonance*. Any device intended to so assist in the production of waves may be called a *resonator*. The importance of resonators is great, and there are many different forms.

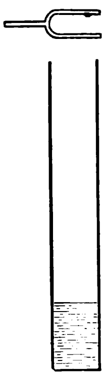

FIG. 128

Fig. 128 shows a tall cylindrical jar containing water. By careful experiment the amount of water may be increased or decreased until a tuning fork, vibrating above its open end, will seem to give out a much louder sound. This is because the air in the jar is set vibrating by the waves from the fork, and these vibrations add to the energy of the original sound waves. Use a fork of *different tone*, and it will be found necessary to vary the quantity of water in the jar, in order to make it serve as a resonator. This shows that an inclosed air column

can be made to vibrate, but *for any given length of air column there is one tone to which it responds particularly.*

It is upon this idea that many musical instruments are built. Fig. 129 shows an ordinary organ pipe. Air forced into it through a small opening causes vibrations in a *reed*, *r*. These vibrations may be of several different rates, but the tube is of a certain length, so that the air in it may respond to only one of the different vibration rates. This one, however, will be so greatly *reënforced by the vibrating air column* that it will be heard far above all the others, and the pipe seems to sound one clear, pure tone.

FIG. 129

Many other musical instruments use the same principle. The cornet, horn, trombone, etc., consist mainly of tubing which serves as a resonator. All vibrations are produced by the lips, assisted by a *mouthpiece*. These set in motion the body of air inclosed by the tubing, and are sufficiently reënforced to produce a loud tone. A set of *valves* or "keys" serves to add bits of pipe to the whole, making it longer or shorter as a tube, and so changing the tone to which it shall respond.

176. Resonators. — Resonators are used whenever it is desired to get a considerable volume of tone, it being better in most cases to have a small vibrating body and a resonator to help out, than to make the body much larger.

Much of the resonance of a body depends upon its shape. A *bell*, for example, causes far more sound waves than if the same quantity of metal were made into a solid block; its parts come in contact with a larger surface of

air. For a similar reason many wind instruments (such as the horn, cornet, etc.) end in a flare or "bell."

A *megaphone* (Fig. 130) acts partly as a *reflector* to keep the waves from spreading all around, and partly as a *resonator*. Being set in motion by the impulse of the original vibrations, its thin walls vibrate, and hitting upon a large surface of air, give rise to additional sound waves. Megaphones are much used for talking at a distance; the so-called "speaking trumpet" has long been familiar to sailors and firemen. Large ones are now used at stations along the coast to send the blast of the fog horn far out to sea.

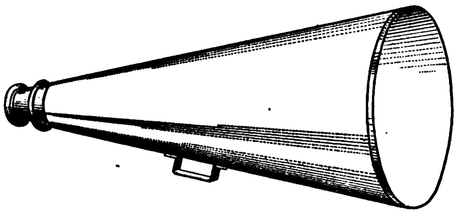

FIG. 130

QUESTIONS

1. What two sorts of vibrations may be caused by another vibrating body? Explain how each is caused.

2. Define forced vibration. Show how it is used in musical instruments. How else may it be used?

3. Define sympathetic vibration. Show why sound waves tend to destroy vibration in bodies having a different rate.

4. What is meant by resonance? What is a resonator?

5. Show how musical instruments make use of resonance. How may the tone sounded by the cornet, for example, be varied?

6. How are resonators used? Upon what does much of the value of a resonator depend? Explain the value of megaphones.

SECTION VII

DIFFERENT KINDS OF SOUNDS

177. Tones. — We know, in a general way, that musical instruments give off clear and, usually, pleasing sounds. Such sounds are called *tones*, and we know by experience that they are very different from the large class of sounds which we may call *noises*. A tone is smooth and agreeable to hear, while a noise is often harsh, discordant, and unpleasant.

The difference is simple. A *tone* is the sound made by *a succession of sound waves striking the ear regularly;* that is, the length of time between the waves is always equal, as they pass to the ear. A *noise* is made up of many different sets of waves, some long and some short, all striking the ear at once.

Let us show this a little more clearly. If a single musical instrument were to sound one note, we should call it a *tone*. The vibrations would be regular, the sound waves would all be alike, and the distances between any two would always be the same. If, now, a whole band should sound all its instruments together, each man making whatever tone he pleased, the result would be a *noise*. The sound waves would be a mixture of all sorts and sizes, and the result on the ear would be a harsh discord.

178. Possible Differences in Tones. — *Tones may differ from each other in three ways, — in loudness, pitch, and quality.*

From what has just been said about the band of instruments, we see that *a noise is simply a discordant mixture of tones;* therefore the pitch and quality of a *noise* would depend upon the pitch and quality of the *separate tones* mixed in the noise. What may be said of tones will therefore apply, in this indirect manner, to noises.

179. Loudness. — This may apply to all sounds, whether tones or noises. We have studied it before and found that it depends upon many things. Among these may be named the *intensity of the original vibrations*, the *distance* of the ear from the source of the waves, the *kind of medium*, the *size of the receiver*, the *direction of the wind* at times, etc.

180. Pitch. — The *pitch* of a tone is usually described by the words *high* or *low*, *shrill* or *deep*. For example, we say the pitch of a woman's voice is usually higher than of a man's; the call of a bird usually has a high pitch, while the bellow of a bull would be said to have a low pitch. Sometimes we hear the word *key* used instead of pitch: one would say a tone is "keyed high," meaning that it has a high pitch.

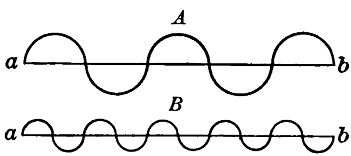

FIG. 131

181. Pitch explained. — Fig. 131 will help us to understand the cause of pitch. We know that vibrations may vary much in length; they may be long or short. We know, also, that in the same medium all

sound waves (whether short or long) must travel with the same speed. For example, the waves in *A* (Fig. 131) must move from *a* to *b* in just the same time as those in *B* move from *a* to *b*, no matter how long or how short each wave is. Thus it is easy to see that the number of sound waves which pass a point in a second may vary greatly according to their size.

The pitch of a tone depends upon how many sound waves reach the ear in a second; the greater the number the higher the pitch.

182. Limiting Pitch. — It must not be supposed that the human ear can discover all wave impulses in the air. Many of these are too long and many too short to be heard. This, however, does not prove that some of the animals cannot possibly hear sounds which escape us.

The limits of pitch which can be heard by man vary much with different persons. Few ears can hear a sound as low as twenty vibrations per second, and many persons cannot hear a tone as high as forty thousand vibrations per second. Doubtless many insects make sounds higher than this, which can never be heard by man.

183. Musical Tones. — *Middle C* (C natural) is usually considered to have two hundred and sixty-four vibrations per second. The *octave* (the eighth tone) *above* would have twice as many, — five hundred and twenty-eight vibrations per second; the *octave below*, half as many, — one hundred and thirty-two per second. The interval between C and the octave above is divided into seven tones, and the whole is called a *scale*.

A man's voice can rarely make a tone lower than one hundred and fifty vibrations per second; but in the shrill cries of children the pitch sometimes runs up into some thousands of vibrations.

184. Quality. — You have perhaps heard a piano and a cornet sound the same tone; it has exactly the same pitch and may be equally loud in both cases, yet there is a difference: you would never mistake a piano tone for that of a cornet. Take any two kinds of instruments you please and try it. No matter if they all do sound the same tone and equally loud, you can always pick out a horn, a wood instrument, a violin, or a banjo, and make no mistake. Each sound has a distinct character, which seems to depend upon *what sort of an instrument* made it; this is what is meant by the *quality* of a tone.

Examples of it are very common. As has been shown, the tones of different instruments sounding the same note may be just alike in pitch and loudness, and yet by their quality we could easily tell one from another. In the same way, two of our acquaintances may speak the same words with just the same pitch and loudness, but we could easily tell the voices apart. It is by the quality of a person's voice that we recognize it.

So there are these three features of a tone, — loudness, pitch, and quality; and if we stop and think, we shall find that all differences in sounds of any sort are due to differences in one or more of these features.

185. Vibration in Parts; Overtones. — A string may be made to vibrate as a whole (*a*, Fig. 132); at the same time it may be vibrating in halves, as in *b*, and also at

the same time vibrations in quarter sections may be made, as in *c*. Or it may be made to vibrate in thirds or in fifths, and so on. That is, a vibrating string *may move as a whole and, at the same time, different sections may have a separate vibration of their own.* In fact this not only may occur, but as a general rule it *does* occur

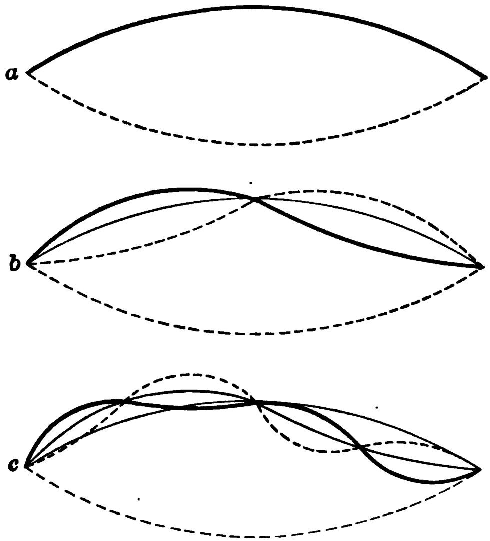

FIG. 132

when any string is vibrating; and further, it occurs in most all vibrating bodies, whether they be strings, air columns (Fig. 133), rods, bells, plates, or membranes.

When any such body is causing sound waves, the tone produced by its vibration *as a whole* is called the *fundamental;* any tone produced by the vibration of a *section* is called an *overtone.*

As a rule we do not easily separate the different tones which thus combine when a note is sounded. This is because one of them (usually the fundamental) is so much more intense than the others that they are not heard. We have heard a whistle sound a low tone for a moment, and suddenly jump to a high shriek; this is because the rush of steam or air becomes too powerful to allow the slower vibrations of the fundamental, and one of the shorter overtones takes prominence. For a similar reason a boy's voice often "breaks."

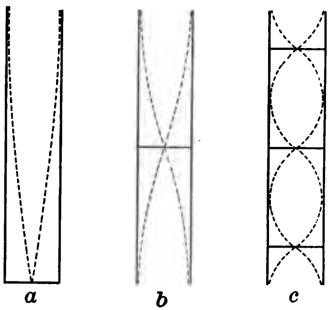

FIG. 133

186. Quality explained. — In the light of these facts an explanation of *quality* may now be understood. It must be remembered that a sound which does not contain any overtones is very uncommon. The fact that we do not hear them, makes no difference; *some overtones are present in nearly every tone*, no matter where or how it originated, and it is the presence of these weak overtones which gives to a tone its *quality*. Therefore, even though they may not be separately heard, the proof of the presence of overtones is shown by differences in quality of tones.

The quality of a tone depends upon what overtones are present and the relative importance of each.

In general, it may be said that pitch depends upon the fundamental, and quality upon the overtones. With

this in mind it is easy to see how two instruments may sound exactly the same note, as to pitch, and yet have a difference in tone which no one could fail to notice.

QUESTIONS

1. Define a tone. Show differences between tones and noises.
2. In what three ways may tones differ?
3. What factors may affect the loudness of a tone?
4. What is meant by pitch? How are different pitches described?
5. Upon what does pitch depend? How do the vibrations of a high and low tone compare?
6. How many vibrations has C natural? What is an octave?
7. State examples of differences in quality of tone.
8. Explain what an overtone is, and how it is caused. What is a fundamental?
9. Explain the cause of differences in quality.

SECTION VIII

MUSICAL SOUNDS

187. Musical Instruments.— Of these there are so many different kinds that we shall have to be content with a brief mention of a few types.

Stringed Instruments. Of these the violin, cello, banjo, guitar, and mandolin are familiar. In each case the sound is made by a *vibrating string* of wire, silk, or gut. The thin wood of the instrument, or the sheep-skin head of the banjo, vibrates with the strings and makes the sound louder. The pitch is varied by tightening the strings or by shortening them, as the player does when he moves his fingers up and down the neck of

the instrument. *Tightening or shortening strings makes the pitch higher.*

The piano and harp are stringed instruments; they have many wires, each being *tuned* to a certain pitch, and the player has only to strike the proper wires.

Wind Instruments. These include horns, cornets, flutes, clarinets, organs, and many others. In each case the sound is produced partly by vibrations of the instrument, but largely by the vibrations of the air inclosed by it. At the opening into the pipe, a mouthpiece or *reed* is set in vibration as the air passes through it, and this makes the *air inside* vibrate also. Pitch depends partly upon the *length and size* of the tube or pipe; quality depends upon the *material* of which the instrument is made, etc.

Tympani. A good orchestra usually includes tympani or kettledrums, together with cymbals, snare drums, triangles, and other instruments which are set in vibration by a blow. The sounds they make are usually *noises* rather than tones, though the noise often works into the music very agreeably.

188. Harmony and Discord. — In the most general sense two or more tones are said to *harmonize* if, when sounded together, they produce a sound which is pleasant to hear. If two or more tones together produce an unpleasant, jarring sound, they are said to be *discordant.*

The subject is too intricate for a very brief study, and must be passed over. It may be said, however, that the unpleasant feature in a *discord* is the quick

succession of beats which are caused by certain combinations of tones.

A *beat* is a peculiar throbbing sensation, due to periods of silence and intense sound alternately following each other at a rapid rate. When the vibration rates of two or more tones are such that, taken together, they produce beats, the combination is called a *discord.*

When a combination of tones is entirely free from beats, the resulting sound is very pleasant, and is called *harmony*. This is a very general view of the subject. A more detailed study is beyond the scope of our present course.

QUESTIONS

1. Name some stringed instruments. How is pitch varied
2. Name some wind instruments. How are the vibrations produced? What reënforces the waves?
3. What are tympani? Name other pieces of similar use.
4. What, in general, is meant by harmony? discord? a beat?
5. How, in general, is the unpleasant feature of a discord produced?
6. Are the beats ever heard in harmony?

SECTION IX

SPEECH AND HEARING

189. The Human Voice. — *The voice is produced by vibrations of the vocal cords.* The air passage (the trachea) leading to the lungs is made of tough rings or bands of cartilage; at its upper end, leading into the throat, is a boxlike structure also made of cartilage, called the *larynx.* At the upper end of the larynx is

the opening into the throat, through which all the air must pass into or out from the lungs, and across this opening are stretched two bands of tough membrane, — the *vocal cords.*

Fig. 134 shows these cords as they appear when not in use, lying loosely on each side, *a*, *a*, of the opening *b*. In this position air passes freely between them, making no sound. When speech is desired, however, the cords are drawn by small muscles till the opening *b* is narrowed to a slit. While they are in this position air is forced outward from the lungs and, passing through the slitlike opening, causes the cords on both sides to vibrate. Thus a sound is produced, which we call *voice.*

FIG. 134

The *pitch* of the voice is varied by drawing the vocal cords more or less tightly. Its *loudness* depends largely on the energy with which the air was forced outward, and partly on the shape of the mouth and throat at the moment. The *quality* of voice depends upon how we arrange the throat, mouth, and nasal chambers, — passages which serve as resonators, and through which the sound waves must come out. Good singing is more a matter of quality than of pitch; a good singer knows how to use his throat and mouth so as to get the best quality of tone. The quality of a person's voice may generally be improved by a little careful effort.

190. Articulation. — *Speech consists in modifying the voice* in one way or another so as to frame words and sentences. The vocal cords simply produce sound waves. Passing through the mouth, these waves are acted upon by the different parts and changed enough so that men may use the different resulting sounds in talking. The so-called "deaf and dumb" usually have vocal cords and can make a noise; they do not talk, simply because,

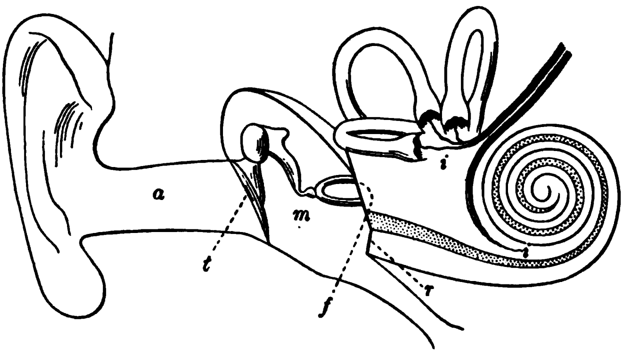

FIG. 135

never having heard speech, they have never learned how to form words with the mouth. We use, in forming words and letters, the tongue, lips, teeth, palate, throat, and nasal cavities.

191. Hearing. — Earlier in the study we learned that sound is the sensation caused by sound waves affecting the *ear*. The ear was also described briefly. Just a word more to show how the ear receives these waves.

Fig. 135 is a drawing which shows the positions of some parts of the ear. In the figure, *a* is the *auditory*

canal, through which the sound waves pass from the outside and strike upon the *tympanic membrane*, *t*. This at once begins to vibrate, its motion being carried through the *middle ear*, *m*, by a series of three bones, to the membrane *f*. Beyond *f* is the *internal ear*, *i*, which contains the ends of the *auditory nerve*. A liquid in the internal ear is set in motion by the vibrations of the membrane *f*, and transmits these vibrations to the nerve endings.

These nerve endings are connected with a sense organ, composed of many hundreds of hairlike *rods*. Each rod is thought to respond sympathetically to a tone having a certain vibration rate, just as each piano wire responds to one (and only one) tone sung outside. Thus the vibrations of the liquid, which have the same rate as the sound waves outside, arouse *sympathetic vibrations* in those rods which respond to that rate, and from them the report is made directly to the brain through the auditory nerve.

This does not give a full description of the ear by any means, but may serve to explain how sound is produced in that organ.

192. The Phonograph. — Several instruments of various style and name have been devised for the purpose of reproducing, at one time or place, the sounds made at another time or place. In all of them the principle is much the same, and a brief study of it may serve to fix in mind some of the new thoughts connected with sound.

The idea is simple. A cylinder of hardened wax (*a*, Plate IV) is caused to rotate by means of a coiled

PLATE IV (FIG. 136). THE PHONOGRAPH

spring. At the same time a recorder, *b*, is made to travel slowly along on a bar, moving lengthwise of the wax cylinder. On this cylinder is a very light groove running spirally around so that it resembles the threads of a screw, only much finer and nearer together.

The *recorder* is shown in Fig. 137. It consists of a thin disk, *d*, attached to which is a point, *c*. The disk is so very sensitive that any vibration of air striking upon its surface will cause a movement of the disk, which will exactly correspond to the vibration in rate and intensity. Of course, as *d* vibrates, it carries *c* up and down with it.

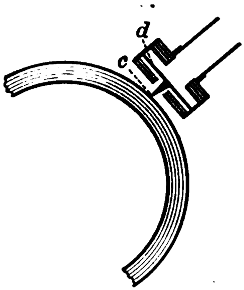

FIG. 137

Now suppose the recorder attached as at *b* in Fig. 136; *a* rotates, and at the same time *b* moves along just far enough so that the point (marked *c* in Fig. 137) shall keep always in the groove, resting lightly upon the wax. Any sound waves now entering the horn will be represented exactly by vibrations of the disk in the recorder (see Fig. 137); but as *d* moves up or down, *c* moves also, and its sharp point marks a series of tiny depressions along the groove of the wax, — one for each vibration, and varying in depth according to the intensity of the sound wave. Thus at the end we have a cylinder whose grooves are full of *irregular depressions, each corresponding to a vibration;* this is called a *record.*

To hear the record, the process is repeated with this one difference, — instead of the recorder a similar device

is used, called a *reproducer*. This is much the same as the recorder, except that its point is not so sharp. As this point now runs over the record, fitting into all the depressions, it must move quickly up and down just as did the point which made those depressions. Being attached to the disk, that also has to move with it, *vibrating just as did the disk in the recorder*. These vibrations of course cause feeble sound waves in the air around the disk; and the horn, acting as a resonator, adds intensity to those waves until the sound may easily be heard at some distance.

QUESTIONS

1. How is the voice produced?
2. Where are the vocal cords? Describe them. How are they made to vibrate? Why do they not vibrate at every breath?
3. How is the pitch of voice varied? How is the loudness of tone varied?
4. By what means can we distinguish voices? Upon what does the quality of voice depend?
5. How is the voice modified in talking?
6. Describe briefly the structure of the ear.
7. By what nerve are the sensations received? By what sort of vibrations?
8. Explain the action of the phonograph.
9. Where are originated those sound waves which issue from the phonograph?

CHAPTER VI

LIGHT

SECTION I

THE NATURE OF LIGHT

193. What is Light? — This is a question which naturally comes to mind at the beginning of our study of the subject, but it is a harder one than we perhaps thought. Scientific men can tell us much about light, — how we may produce it, through what bodies it may be carried, and many things about its behavior. But when it comes to saying just what light really *is*, we find a question not easily answered. The best we can do, then, is to content ourselves with the "theory of light," which, though not really proved, seems to give a reasonable answer to the question.

194. The Theory of Light. — Some time ago we learned a "theory of heat"; we could not say for sure that it was true, but it was a reasonable explanation of the cause of heat, and seemed to give a satisfactory answer to most questions about the subject. It is much the same with light. We cannot say definitely that this theory is true, and perhaps it is even harder to prove than that of heat; but after all, the *theory of light*

furnishes an explanation which seems reasonable, and it is at present the best we can do.

The theory says, in substance, that *light is caused by luminous bodies, which send out vibrations that may affect the eye.* A *luminous body* is any substance which is giving out light from itself. The vibrations which are given off from a luminous body are called *light waves.* The effect of these light waves upon the eye produces *sight.*

This explanation of light would seem to be very much like that of sound. There is some difference between the two in one respect, however, for the cause of sound is a proved fact, while with light we have only a theory. As has been said, there is no better explanation of light, and really we have many good reasons to believe the one given. It simply says that luminous bodies in some way send off vibrations or light waves, which may act upon the eyes to produce sight; but just *what* it is that is given off, and *how* it is done, are questions which man has not yet solved.

195. Luminous and Illuminated Bodies. — *A luminous body is one which sends out light waves from itself.* This means that the light waves have their *origin* (starting point) in the luminous body.

An illuminated body is one which is seen by the light waves which shine upon it from some luminous source. The rays sent off from it are none of them originated in the body, but are only such as strike its surface and "glance" off.

A bit of thought will show that in our common experience nearly all objects are seen because they are

either luminous or illuminated; in other words, they either *send out light waves from themselves*, or *send off the waves which are falling upon them* from some luminous body. The sun is a luminous body, shining by its own light. The moon is an illuminated body, sending off only the waves which fall upon it from the sun.

Some objects may seem to be more brightly illuminated than others in the same light. This is because many substances do not send off *all* the light waves which fall upon them. Those waves which are not sent off by the object are said to be absorbed, *i.e.* taken into the substance.

196. Phosphorescence and Incandescence. — Some substances seem to have the peculiar property of taking in (absorbing) light waves which fall upon them, and giving them out some time later. The waves may store up a certain sort of energy in the substance, so that when left in darkness the body itself seems to be a center from which light waves are started. This property is called *phosphorescence.* A certain so-called "phosphorescent paint" has been made; anything coated with it will emit a dim light at night, which may be seen for short distances.

A body whose molecules are moving so rapidly that it becomes luminous, is sometimes said to be in a state of *incandescence.* An iron bar heated to a bright red, is a common example of this. The carbon filament in a small electric light becomes incandescent when it is heated by the current passing through it; in this condition it becomes a source of light waves.

QUESTIONS

1. Briefly state the theory of light. Compare this with sound.
2. What is a light wave? What is the source of a light wave?
3. How are we able to see objects?
4. When may a body be called luminous? What relation seems to exist between luminosity and heat?
5. What is an illuminated body? Name some luminous and some illuminated bodies. Can we see by the light of an illuminated body?
6. What is phosphorescence? incandescence?

SECTION II

SOURCES OF LIGHT WAVES

NOTE. — This section is supplementary, and may be omitted without detracting from the completeness of the course.

197. The Sun. — By far the most important source of light to us is the sun. The sun is a gaseous body, consisting of many different substances in a highly heated state. Nothing at all definite is known concerning the interior of the sun.

198. Artificial Lights. — The number of substances which are used as sources of artificial illumination, although great, may really be grouped under very few heads, — wood fires, torches, candles, oil lamps, gasoline burners, and various gas burners. Electric lights are now common, and they are fully treated later.

Of the subjects mentioned, we may note first that in all devices (except electric lights) something is *burned*. This means (§ 129) that in every case some substance is

used which may unite with oxygen if its temperature be raised.

It may also be noted that the substances used may be grouped into three classes, —*products of wood*, *oils*, and *gases*. A further study of these substances would show that they all contain large quantities of two elements, — *hydrogen* and *carbon*. Before studying each substance in detail, let us see how these two elements are important.

199. Flames. — *Hydrogen* is a gas. It is very common in nature, being one of the two elements (hydrogen and oxygen) in water. It burns very readily, giving off great heat.

Carbon is a solid element. It is also common, being an important factor in most vegetable matter. Charcoal and coke are impure forms of carbon. It unites with oxygen at high temperatures, but not as easily as hydrogen.

Now when heat is applied to wood, an oil, or a gas, which contains hydrogen and carbon, the substance is decomposed (§ 127), and these two elements are set free. But the hydrogen (which easily unites with oxygen) begins to burn. The burning gas makes heat enough to warm up the solid particles of carbon till they glow, and this makes the flame *luminous*.

The flame is kept up because the burning hydrogen supplies heat enough to decompose more of the substance.

200. Wood Fires; Torches. — Wood or vegetable matter, pitch, resin, etc., all contain large amounts of carbon and some hydrogen; hence they will of course burn. The flame will be fairly luminous, but is usually very *smoky*. This is because there is not enough hydrogen

present to cause sufficient heat to burn up all the carbon, the unburned particles forming the smoke.

201. Petroleum. — A natural oil in a very crude form comes directly from the ground in some places. This oil (*petroleum*) is put through a process of "refining," as a result of which we get several substances. Among these are kerosene, gasoline, and paraffin, all being rich in carbon and hydrogen.

Kerosene is widely used to-day in *oil lamps*. The oil is raised to a burner by means of a wick; a chimney provides for a good draught. If the wick be up too high, the lamp "smokes," because the carbon is supplied faster than it can be heated.

Paraffin is a solid white substance. It is used in making *candles*.

Gasoline, a liquid which changes easily to a gas, is used by means of special burners. The gasoline is kept in a tank, from which it runs to a coil in the burner. Here it is heated and led out to the flame in the form of a gas.

202. Illuminating Gas. — Coal is simply vegetable matter which has been in the earth for long ages and has lost some of its elements.

If coal be heated in a vessel which is closed so as to admit no air, the gas which comes off will contain a considerable amount of hydrogen and carbon. Of course, if air were let in to the heated coal, this gas would at once burn up. As it is, however, the gas is run through water (which takes out some of the substances that will not burn) and is stored in large tanks. From the tanks

it is forced through a system of pipes and carried all over cities to be burned. This is ordinary *illuminating gas.* It contains the same two elements, and burns with little smoke usually.

Natural Gas. In some places a natural gas comes from the earth and is used to supply cities. It is obtained, like petroleum, by boring into the earth.

This does not complete the list of substances which may be used, but may give a clearer idea of common sources of *luminosity.*

QUESTIONS

1. What is the great source of light waves upon earth? What sort of substance is the sun?
2. Name several substances commonly used to produce light artificially. Under what general heads may they be classed?
3. What two substances have an active part in common flames? Describe each. What is the particular use of each in the flame?
4. What is petroleum? What common substances are made from it?
5. Of what is a candle composed? How is gasoline used as an illuminant?
6. What is coal? How is illuminating gas obtained from coal?
7. What is smoke? Why does a lamp "smoke"?

SECTION III

HOW LIGHT TRAVELS

203. Rays. — *Every point in a luminous body sends off light waves in all directions* (Fig. 138).

Any single light wave travels in a straight line from its source. Its *direction* is of course marked by a single line, as *oa*, for example, which is called a *ray.* A number

of parallel rays from the same source are together called a *beam* (Fig. 139).

We commonly speak of the ***sun's rays***, meaning, of course, the light waves from the sun. It is quite right to use the word *rays* in many cases, though when we speak of something which can be seen, *beam* is the word to use. We cannot see a "ray of light through a keyhole"; *a ray has only direction* (but no width or thickness), and the beam that goes through a keyhole contains an infinite number of rays.

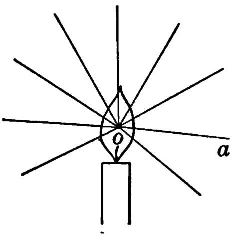

FIG. 138

204. Media. — We learned that sound waves do not pass through a vacuum; do light waves? Yes; very easily. Then the question at once comes up, Do light waves require *any* medium?

Before answering this let us think a moment. In the first place, it is not possible to get a perfect vacuum on earth; the best vacuum man can make is not to be compared with the space between the earth and sun for rarity — that is, after we get above the earth's atmosphere. This empty space must be very rare, for if the gas in it had much density, it would gradually stop the motion of the earth, just as friction of the air stops a thrown ball in time.

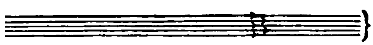

FIG. 139

Nevertheless, if our theory is true, there must always be some sort of a medium to carry the vibrations or

light waves, and men feel so sure of this that they have gone far enough to name the medium which carries the waves; they call it *ether.* This must not be confused with the ether we buy in bottles; no one has ever seen "the ether," and the word is used as a convenient expression for that which transmits vibrations.

We may say, then, that without any reasonable doubt light waves do require some medium, but this medium may be very rare. *Light waves travel faster in a rare than in a dense medium.*

205. Radiant Energy: the Ether. — Exactly as heat may be carried by radiation, it is assumed that light rays also are transmitted. In fact, scientists generally do not recognize any difference in the *kind* of radiations, but only a difference in the *effect* which they produce in various bodies.

It is customary, then, to say that light *radiates* from a luminous source, or travels by *radiation.*

As has been shown, men do not know how the luminous particles act upon the medium or how the particles of the medium act upon each other, but inasmuch as motion takes place, there must be energy involved; and this sort of energy, which is transmitted by radiation, is called *radiant energy.*

This is a subject which of late years has received much attention from scientific minds. Various experiments in wireless telegraphy and also the so-called X-ray have given rise to many new ideas on the subject and opened up new lines for study. We shall take up these subjects later; but for the present it may be

well to note, in passing, the importance and meaning of radiant energy and of the ether.

A vast amount of energy from the sun comes to earth daily, though the earth receives only a very small proportion of that which travels from the sun into space. The medium which transmits this energy through space is called *ether*. Through the ether, then, energy travels by radiation, and arriving at different receivers this radiant energy may produce one effect or another, according to the nature of each receiving body.

206. The Passage of Light Waves. — *Some substances allow light waves to pass freely through them;* glass, air, and water are examples. We can see through them clearly, and hence they are called *transparent* bodies.

Other substances allow the light waves to pass through, but scatter the rays in passing. On this account we cannot see through them to distinguish objects. Such bodies are said to be *translucent.* Ground glass and oiled paper are translucent; they let light through very easily, but we cannot see through them.

Opaque bodies are those through which light waves do not pass at all. Iron, wood, leather, earth, etc., are opaque. It is clear that when light rays fall upon an opaque body, one of two things must happen: either the waves will be taken into the body itself and stop there, or they will strike its surface and bound off again, as in a looking-glass. If the waves are taken into the body, they are said to be *absorbed;* if they hit its surface and bound back, they are said to be *reflected.* We shall study "absorption" and "reflection" later.

207. Velocity of Light Waves. — In studying sound we noticed that one often *sees* an act some time before he hears the noise resulting from it. This shows at once that light waves travel faster than sound waves; we perhaps remember that the sound waves move only 1125 feet per second. It has been found that *light waves travel about 186,000 miles per second.*

This number was found in an interesting way. One of the moons of the planet Jupiter was seen to revolve about the planet, passing behind it at regular intervals. The time at which it would do so could be calculated with great exactness for a long time ahead. Now when

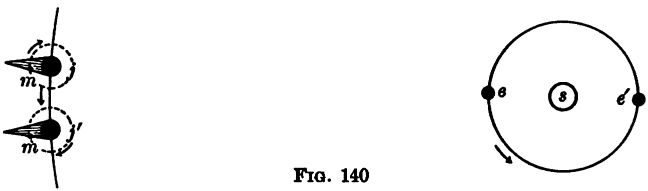

FIG. 140

the earth and Jupiter were on the same side of the sun (*e* and *j*, Fig. 140), the exact minute of the moon's passage could be foretold for some time about six months later. At that time (six months later) the earth would be on the other side of its orbit, at *e'*, and Jupiter would have moved to *j'*. In this position it was found that the moon *m* did not pass behind Jupiter at the moment foretold, but about *a thousand seconds later* (16 m. 36 sec.). *This lateness was due to the length of time which the light waves needed to cross the earth's orbit* from *e* to *e'*, a distance of 186,000,000 miles. Thus, if it took a thousand seconds for light waves to go 186,000,000 miles, they must have traveled at a rate of 186,000 miles a second.

208. Examples of the Speed of Light Waves. — The speed of light waves is so great that for any distances which one can see on earth it amounts practically to our seeing anything instantly. It would take only one seventh of a second for a light wave to go entirely around the earth.

When the distances are very great we can see a little more clearly that it does take time for the waves to travel. For instance, the *sun* is 93,000,000 miles away, and it takes *eight minutes* for its light to reach us; light from the *moon*, 240,000 miles away, comes to us in a little more than *one second.*

The distances between stars are so great that astronomers often express them in terms of "light-years." A *light-year* is the distance a ray of light will travel in a year. When we stop to think of it, this is a very long way (186,000 miles × 31,500,000). The nearest star which has been measured is between three and four light-years away; some are over a hundred, and many are farther. The light which we see from some stars at night is due to waves which were started long before the American Revolution.

209. Intensity of Illumination. — The intensity of light, or more properly intensity of *illumination*, of course decreases as we go farther from the source of the waves. The reason is, the same as for sound, that *the waves must spread over a greater area.*

In Fig. 141 let *a* be a source of light waves and the lines *ab*, *ac*, *ad*, and *ae* represent four rays, each making equal angles with the two beside it. From points *b*, *c*,

d, and *e*, equally distant from *a*, draw the figure *bcde*; since the angles at *a* are equal, this figure must have equal sides. It is clear also that all rays included by *ab*, *ac*, etc., must, at the distance *ab*, strike the figure *bcde*. Now at a point, *f*, twice as far from *a* as is the point *b*, draw another figure whose sides shall be parallel to *bc*, *cd*, etc. Since *f* is twice as far from *a* as is *b*, each side of the figure at *f* will be twice the length of *bc*, *cd*, etc.; that is, the area inclosed by the four rays will be four times as great at *f* as at *b*. Thus the rays

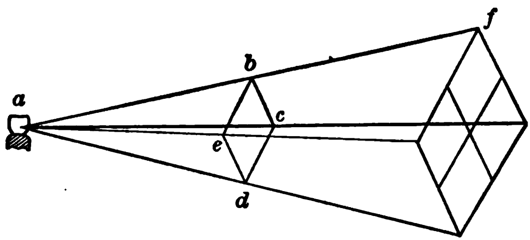

FIG. 141

at twice the distance have to cover four times the area; and since there are no more rays at *f* than at *b*, any spot on the figure *f* will receive only one fourth as many rays as a spot the same size on *bcde*. Therefore at twice the distance the illumination is one fourth as great. From this we derive the following law:

The intensity of illumination decreases as the square of the distance increases.

210. The Size of Objects; Visual Angle. — The angle formed by two rays when they enter the eye is called the *visual angle*. In a way, the visual angle formed

between two rays from the two extreme points of an object helps us determine the size of the body.

Supposing the eye to be at the point *e* in Fig. 142, the angle *aeb* is the visual angle formed by the rays from the extreme points of the object *ab*. If we knew that the object *cd* was at the same distance from the eye as *ab*, we should at once know that *cd* is larger than *ab*,

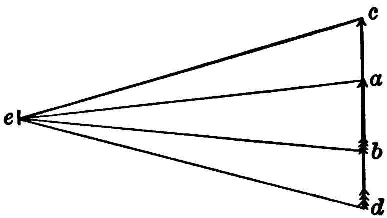

FIG. 142

because the visual angle *ced* is greater. In Fig. 143, however, we have an object, *cd*, which is evidently equal to *ab* in size, but which would appear to be larger because its visual angle *ced* is greater than the visual angle *aeb*. *The nearer the object, the greater its visual angle.* From this we see that when two bodies are at the same distance from the eye, their relative size may be determined by comparing their visual angles.

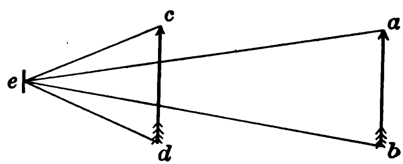

FIG. 143

It is also clear that to judge the size of objects we must know something of their *distance* from us. To one who knew nothing of their distances, the sun and moon might seem to be about the same size, having about the same visual angle. Our judgment of distance by the eye is generally a matter of training; a landman has a poor idea of distances at sea.

QUESTIONS

1. What is a ray? In what sort of line does a ray travel?
2. What is a beam? How does light travel from a luminous point?
3. Do light waves travel through a vacuum? Do sound waves?
4. What do we call the medium which transmits light waves?
5. How does the density of medium affect the passage of light waves?
6. How may we describe "the ether"?
7. What is meant by radiant energy? What is it which travels when energy is transmitted by radiation?
8. What is a transparent body? Give examples.
9. What is a translucent body? an opaque body? What becomes of the light waves which fall upon an opaque body?
10. How fast do light waves travel? How is this determined?
11. What is a "moon"? What is the "orbit" of a planet? How far away is the sun? How long are the sun's rays in coming?
12. What is a light-year? How is it used to measure distances?
13. State the law for the intensity of illumination. Explain why this should be true.
14. What is the visual angle?
15. Upon what do we base judgments of size of objects?
16. How does the visual angle vary?

SECTION IV

SHADOWS

211. Darkness. — Darkness is simply absence of light. A place is in darkness when opaque bodies come between it and all sources of light waves which might enter it. Now when an opaque body cuts off rays of light, it is said to cast a *shadow;* that is, the portion where no

light waves fall is called the shadow. So darkness and shadows are alike in that respect.

At night it is dark because we are in the shadow of the earth. It does not grow dark at once after sunset, nor stay dark till sunrise, because some of the sun's rays are reflected down to us for a time from the air above; as soon as the sun ceases to shine on that air, darkness falls.

Very much depends upon this reflection of light by air particles. It is perfectly easy to see in the daytime,

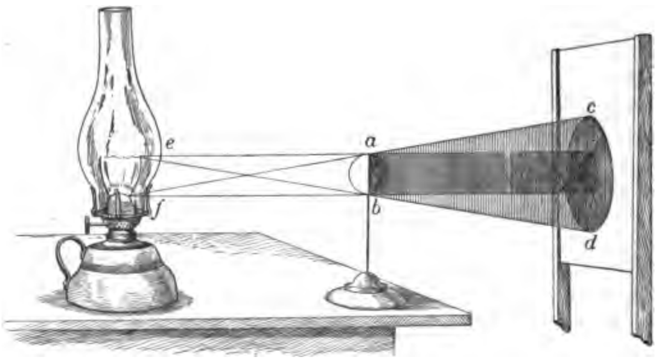

FIG. 144

though one is in the shade of a tree, wall, or building; there is plenty of light in a room, even though the direct rays from the sun may not enter a single window. This is all because of the *reflection of sunlight* from air, dust, moisture, and any other particles in the atmosphere. If it were not for such reflection, all places would be in darkness except those upon which the sun's light rays actually shone.

212. Shadows. — Many shadows have a dark central portion called the *umbra*, and a lighter portion near the

outside edge called the *penumbra*. Fig. 144 shows how each is formed. All outside the lines *fc* and *ed* is in the full light; points inside the lines *ac'*, *bd'*, *ab*, and *c'd'* are entirely in shadow, and hence that part is the umbra. All points outside *ac'* and *bd'* and inside *ac* and *bd* are in the light from part of the flame, but cut off from some of the rays; therefore the parts named form a sort of fringe to the shadow, gradually growing lighter till the outside is reached. This is the penumbra.

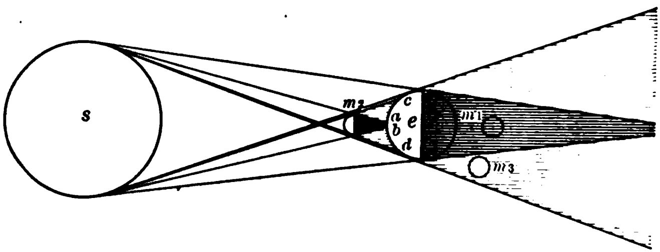

FIG. 145

213. Eclipses. — Fig. 145 shows how eclipses of the sun and moon are dependent on shadows. In the figure, *s* is the sun and *e* the earth. An *eclipse of the sun* is caused by the moon, which passes between the sun and earth. All points on *e* between *c* and *d* would see the sun *partially eclipsed*, but only those in the umbra of the shadow *ab* would see a *total eclipse*. When the moon passes through the umbra of the earth's shadow, m_1, we see a *total eclipse of the moon*. A *partial eclipse* would occur when it passed through the penumbra, m_3. From the figure it is evident that a total eclipse of the sun will cover but a small portion of the earth's surface.

QUESTIONS

1. What is meant by darkness? Why is it dark at night?
2. Why does not darkness begin at once with sunset? Explain why it is light in daytime even in "the shade" and in buildings.
3. What is the umbra of a shadow? the penumbra?
4. What is an eclipse? How is an eclipse of the sun caused? an eclipse of the moon? Would the sun be eclipsed on a full or new moon? How is it with the moon's eclipse?

SECTION V

REFLECTION OF LIGHT WAVES

214. Definition. — *Reflection of light is the bending of a ray when it strikes a surface and comes off.*

In the study of echoes we found that sound waves are sometimes reflected; that is, when they strike a surface, they are bent back or turned off from it. In just the same way light waves are often turned off from a surface; this is called *reflection.*

215. Law of Reflection. — The law of reflection is simply a statement of how the light waves behave when they strike a surface and are turned back. To understand it, suppose yourself standing at *a* (Fig. 146), looking into a glass mirror, *cd*. It is clear that as you are directly in front of the glass, light rays will pass from you to it along the line *ab*, meeting the glass at right angles. Thus the rays, striking *at right angles* at *b*, will come straight back along *ba*, and you will see your own reflected image.

If now you move to *f*, keeping your sight on the point *b*, you no longer see yourself but some other object at the point *e*; that is, the rays going from *e* to *b* are reflected from *b* to *f*. Now measuring the angle *cbe* we find it to be equal to the angle *dbf*. If *f* had been any other point in front of the looking-glass, the result would have been the same; that is, angle *cbe* would always equal angle *dbf*. The fact is expressed in the following statement of the *Law of Reflection:*

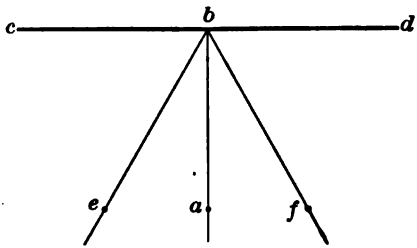

FIG. 146

The angle at which rays strike a surface always equals the angle at which they are reflected.

216. Reflection from Smooth and Rough Surfaces. — We have learned that some surfaces absorb light waves and others reflect them. Now of surfaces which reflect light there are several sorts, but we may notice those which reflect *images* and those which simply reflect *scattered light waves.* Almost any polished metal surface, polished wood, glass, or smooth water will reflect images; while a plaster wall, white cloth, or snow will reflect light waves but not images. The reason for this is simple

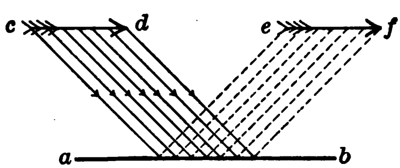

FIG. 147

if we bear in mind that the surfaces which reflect images are very smooth.

When parallel rays strike a smooth surface, all will be reflected *at the same angle* and an image will be formed, as in Fig. 147. Here *ab* is a smooth surface; rays from an object, *cd*, strike *ab* and are reflected along the dotted lines, forming an image at *ef*.

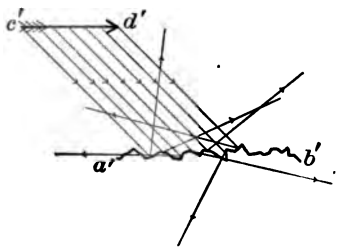

Fig. 148

But surfaces like cloth, snow, running water, etc., are somewhat rough. They may not be very rough, but if we remember that each ray is but a *line* striking a surface in the tiniest sort of a *point*, we see that the rays may strike a rough surface so as to go off *at different angles.* In Fig. 148, *a'b'* shows a rough surface: the parallel rays from *c'd'* strike it at different angles and are *scattered* in all directions, so that no image can be formed.

217. Mirrors and Reflectors. — Polished surfaces, particularly metal surfaces, get dull in time and do not reflect well. This is because they become covered with thin layers of other substances, which absorb the rays. Scouring with a polishing substance removes the layer and brings out the bright metal surface again.

Mirrors are usually made by covering glass with mercury or silver. It is the surface of the metal which reflects; the glass simply protects it from the air, and affords a surface on which it may be spread.

The *moon* shines by reflected sunlight. It gives off no light of its own, and all the rays which come from it are light waves from the sun, which have struck the moon and been reflected to the earth. The same is true of the *planets*. But all the great number of *stars* shine by their own light, being really suns much like our own, only very far away.

218. Reflection from Curved Surfaces.—We have so far considered the law of reflection with regard to *plane* surfaces. In studying the behavior of light waves striking *curved* surfaces, this fact must be borne in mind:

A light wave is reflected from a curved surface exactly as if it struck a plane, tangent to the surface at the point of contact.

A word may make this clearer. The *tangent* is a line which touches a curve at one point only, and does not cut the curve at all. In Fig. 149, *ab* is tangent to the curve *ef* at *c*; the point *c* is common to the straight line and the curve, but at no other point can *ab* touch *ef*; and it follows that the angle *ace* is equal to the angle *bcf*. If now a ray should strike the curved surface *ecf* at the point *c*, no matter where it came from, it would be reflected just as if it struck the plane surface *acb*.

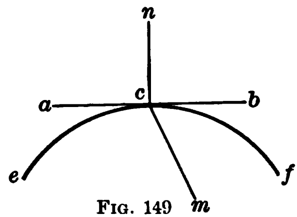

FIG. 149

219. Concave Mirrors.—A *concave* surface curves inward. Fig. 150 shows a concave surface, *acb*, used as a mirror. The point *c* is called the *vertex* of the mirror; *p* is the center of the figure, of which the mirror is a part of the surface; *pc* is called the *principal axis*. It is

evident that any single ray from any part of *pc* which meets the mirror at *c*, will be reflected back along the same line *cp*.

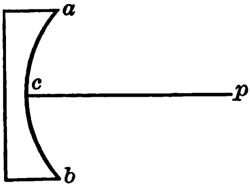

FIG. 150

By constructing several tangents to different points on a concave mirror (Fig. 151) it may be shown that *parallel rays are all reflected to a certain point*, f, *on the principal axis.* This point is called the *principal focus* of the mirror. The sun's rays, or those from a distant body, being nearly parallel, would be reflected approximately to this point, and here the light would be more intense.

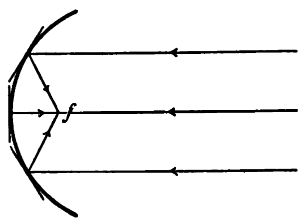

FIG. 151

In the same way it may be shown that *if a luminous body be placed at the principal focus, its rays will be reflected from the mirror in parallel lines* (Fig. 152). Many reflectors are made on this principle. A glance is enough to show how great is the advantage, for all the rays which would escape at the sides and back of the luminous point are caught and turned in the direction where they are most needed.

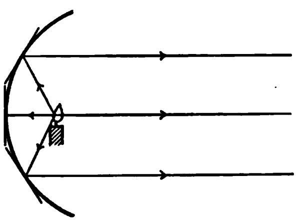
FIG. 152

With a mirror which is carefully made, a very strong light may be directed on an object, even though the luminous body be comparatively

weak. *Search lights* are very much strengthened by the use of large reflectors. The *headlights* of locomotives have concave mirrors, which are very carefully constructed, so that a strong light may be directed on the track, even though in many cases only a common oil lamp is used.

It is in their service as reflectors that concave mirrors are most useful. *Convex* (or outward-curving) mirrors are made, but are not so widely used as the concave.

QUESTIONS

1. What is meant by reflection of light waves? State the law.
2. Where would you have to stand to see your own reflection in a plane mirror? Can you see the reflection of some one else in a mirror, even though you cannot see your own? Why? Can he then see you?
3. What sort of surfaces may be used as mirrors? Why will not a rough surface serve this purpose?
4. What is a reflector? Why may some surfaces serve as reflectors which would not do for mirrors?
5. How is a ray reflected from a curved surface?
6. What is a concave surface? What is the principal focus?
7. What is the advantage of a concave reflector?
8. Name some uses of concave reflectors.
9. In using a concave reflector, where would the light be placed in order that the reflected rays may be parallel?
10. How is an ordinary mirror made? Which part of the mirror reflects the rays? Think of some way to prove this.
11. What becomes of the light waves which strike an opaque body and are not reflected?
12. In looking into a plane mirror, how far away does your image seem to be? Why is this? Does it seem to be in front of or behind the mirror?

SECTION VI

REFRACTION

220. What is Refraction? — When light rays strike a body, one of three things may happen to them: they may go through it, they may enter the body and stop, or they may strike its surface and bound back. If they bound back from the surface, we say they are "reflected"; if they stop in the substance, they are said to be "absorbed." But sometimes when light waves enter one substance from another, they are bent somewhat out of a straight line, and to this change of direction we give the name *refraction*.

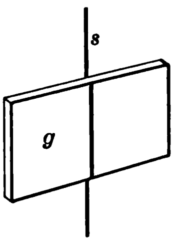

FIG. 153

Examples of refraction are familiar. It is not uncommon to see a pole apparently bent at the point where it goes into water. If you hold a piece of thick glass over a string or pencil so that the line from your eye to the glass meets its surface at a sharp angle, the string will appear broken, as in Fig. 153; or if you look at a penny in the bottom of a dish of water with your eye at *e* (Fig. 154), the coin will seem to be at *p*. In each of these cases notice that the light waves passed through two different media and were bent *at the point where they passed from one to the other.*

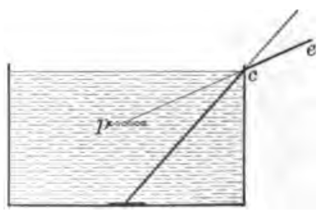

FIG. 154

221. Refraction defined. — Let us remember this for a moment while we consider the matter further. In all these cases mentioned, we notice that the rays from the object to the eye meet the surface between the two media at an *acute angle* (an angle less than a right angle, — 90°). Now look straight down to the penny, so that the line *ep* from the eye to the coin hits the surface of the water at right angles (Fig. 155), and we find that the rays are not refracted at all.

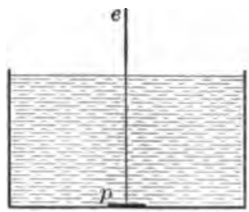

FIG. 155

Also, look through the glass again, but hold it so the line from your eyes hits the surface of the glass at right angles; there is no bending of the rays (Fig. 156). So we see that the rays are not refracted if they meet the surface between the two media at right angles. In other words, *refraction occurs only when the rays cut the surface between the media at an acute angle.*

Combining this fact with what we just discovered in the previous section, we may say:

Refraction is the bending of light rays when they pass from one medium to another of different density, at an acute angle to the surface between the media.

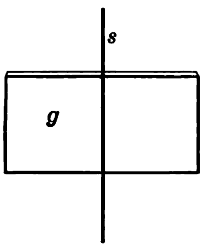

FIG. 156

222. Explanation of Refraction. — To understand refraction we must fix in mind this principle: *Light waves travel faster in a rare medium and slower in a dense one.*

In Fig. 157 let *mn* be the surface between a rare medium, *R*, and a dense one, *D*. Parallel rays run from the object *ab*, and *cd* shows the position of these rays when those near *bd* reach the dense medium. Now, because they are in a *denser* substance, the rays *bd* will travel only from *d* to *f* while those near *ac* are going from *c* to *e*; so when all the rays are in the dense

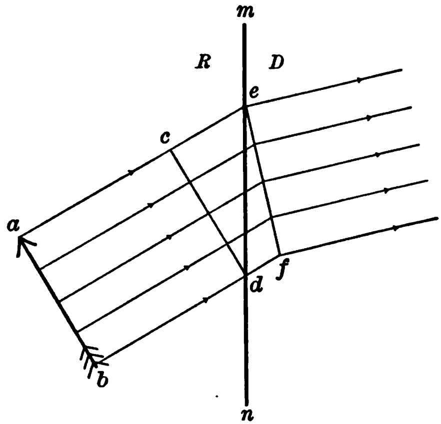

FIG. 157

medium, they will have the position *ef*. From this position they will go on again, all at the same speed so long as they are in the same medium; but their *direction* will have been changed at the line *mn*.

It is clear that if the rays *ac*, *bd*, etc., struck *mn* at right angles, all would get there at the same time and there would be no refraction.

Definition. The line *cd* (Fig. 157), for example, includes all vibrating particles which are at a certain

distance, as *ac*, from the object *ab*; that is, all particles included by the line *cd* are in the same state of vibration. A line which includes all points in the same state of vibration is called a *wave front*. The line *cd* is a wave front; passing into the denser medium, the direction of the wave front is changed to the position *ef*.

223. The Prism. — Glass, being a transparent medium and denser than air, is commonly used as a refractive agent. One of the simplest forms in which glass is so used is the *prism*, shown in cross section in Fig. 158.

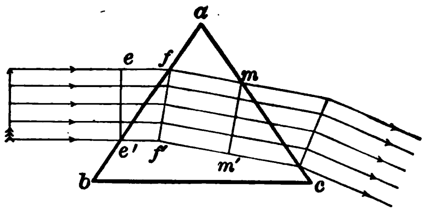

FIG. 158

Remembering the explanation in the last paragraph, it will not be hard to understand the behavior of the prism toward light waves. The wave front *ee'* meets the face *ab* of the prism at an acute angle, as shown in the figure. The glass affording a denser medium than air, the wave front is turned to the position *ff'* and the waves are refracted. Soon the wave front *mm'* meets the face *ac* at an acute angle, and going from a denser to a rarer medium, the wave front again takes a new direction. So the waves continue on, having been twice bent or refracted, *once on entering and once on leaving the prism.*

224. Lenses. — Another form of glass for purposes of refraction may be perhaps more familiar, — the *lens.*

The difference between the prism and the lens is mainly that a lens has *curved faces*, instead of the plane faces of a prism. That they are really very much alike in nature is shown in Fig. 159. Both shapes of lens are shown to be very much like two prisms, differently put together. If this fact is kept in mind, together with the explanation of prisms in the last paragraph, there ought to be no difficulty in understanding how light waves are refracted by lenses.

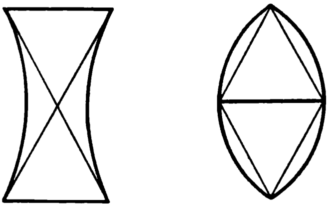

Fig. 159

225. Shapes of Lenses. — The names *concave* and *convex* have already been applied to surfaces and defined; the word *plane* is of course familiar as a "flat" surface.

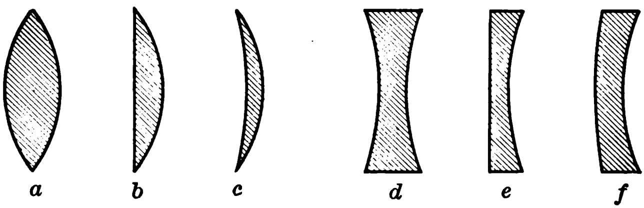

Fig. 160

Fig. 160 shows the *six* possible shapes of lenses made by combining these three surfaces. The figures are of course cross sections. Of the lenses, *a* is called *biconvex*, having its two faces convex or curved outward; *b* is

plano-convex, one face being a plane and the other a convex curve; *c* is *concavo-convex*, one face concave and one convex, but thicker at the center than at the edges; *d* is *biconcave*, both faces curving inward; *e* is *plano-concave*, one plane and one concave face; *f* is *convexo-concave*, one face convex and one concave, but thicker at the edges than at the center.

226. Names of Parts. — Fig. 161 shows the cross section of a biconvex lens. The distance *ab* is the *diameter* of the lens; the point *c* is the *optical center.* The line *pc*, perpendicular to *ab* at the optical center, is called the *principal axis;* any other straight line passing through the center *c* is called a *secondary axis.*

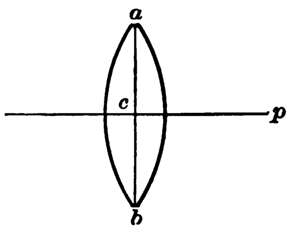

FIG. 161

Other substances besides glass may be used as lenses. It is only necessary to have some transparent medium, one of whose surfaces, at least, is curved. Water, ice, or transparent rock could be used, though for almost all common purposes lenses are made of glass. All sizes of glass lenses are made and variously used. The largest are mounted in telescopes for astronomical work; these are made at great expense of time, labor, and money: a single lens may require years of work. The largest now in use is forty inches in diameter, mounted in the Yerkes Observatory in Wisconsin.

227. The Effects of Lenses. — The lenses *a*, *b*, and *c* in Fig. 160 may be classed as "convex," and *d*, *e*, *f* as

"concave." That is, there are two general ways in which a lens affects light rays; and all convex lenses would have like effects on the rays, as compared with the effects of all concave lenses.

In general, the effect of convex lenses is to make the refracted rays converge, *i.e.* bend toward each other (Fig. 162).

The effect of concave lenses is to make the refracted rays diverge, *i.e.* spread away from each other (Fig. 163).

228. The Focus; Explanation. — *The point at which converging rays meet is called a focus.* Rays parallel to the principal axis will be refracted toward a point on the axis called the *principal focus* (*f*, Fig. 162).

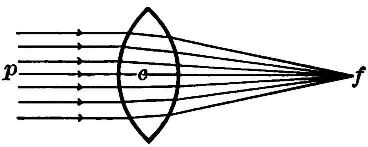

FIG. 162

Fig. 162 may help explain how rays are brought to a focus by means of a lens. From the figure it may be easily seen that the principal axis, meeting both surfaces at right angles, will not be refracted (*pcf*). Rays parallel to *pc* above it are refracted down toward it, and those below are bent upward; that is, *all rays parallel to the principal axis are refracted toward it.* Now both surfaces of the lens curve exactly the same on either side of *pc*, so that any ray above the principal axis will be refracted just as much as the ray which is the same distance below. Also the angle at which each ray meets the lens changes just enough so that, whatever its distance from *pc*, each ray is refracted to the same point. It would be well to make a careful study of this, so as to thoroughly understand the effect of the convex lens.

229. Convex Lenses. — The following statement, from § 228, needs no proof. *Rays parallel to the principal axis are all refracted to nearly the same point.* It makes but a very slight difference how far the source of the rays may be from the lens, so long as they are parallel.

Rays from a point to a lens will *diverge* as they approach it; a little thought will show that they will not be refracted so sharply on leaving the lens. Therefore *rays which diverge will, on entering a convex lens, be refracted to a focus back of the principal focus.*

When the source of light waves is larger than the lens, the rays may have to *converge* on approaching it. *Rays which converge will, on entering a convex lens, be refracted to a point nearer the lens than the principal focus.*

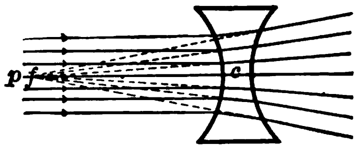

Fig. 163

230. Concave Lenses. — Fig. 163 shows how parallel rays *diverge* after passing through a concave lens. Rays from *p* pass through the lens *c*. As explained in § 228, the principal axis *pc* is not refracted. The rays on either side of it are refracted on entering and leaving the lens, being in every case bent *away from the axis.* The point *f*, from which the refracted rays *seem* to come, is the focus of this lens. As the rays do not really come from this point, it is called a *virtual focus.*

231. Refraction of Heat Rays. — It may be noted, in passing, that lenses have the same effect upon *heat radiations* as upon light rays.

Fig. 164 shows a simple convex lens used as a "burning glass,"—converging the sun's rays upon a point. The point *f* is clearly the principal focus of the lens. At that point is a spot of intense illumination; the hand held there finds it uncomfortably warm as well. The heat is great enough to burn a small hole in paper, and a bit of gunpowder placed there would quickly be exploded.

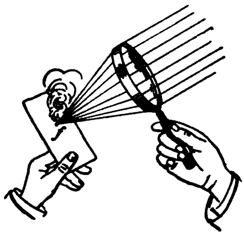

FIG. 164

The fact that the spot is intensely *luminous* and *hot* may be taken as an example of what has been stated before (§ 205), that heat radiations and light waves are really the same. The difference is considered to be only a difference in *effect* and in *wave length.*

QUESTIONS

1. What is meant by refraction? Name common examples.
2. Under what conditions are light waves refracted?
3. Explain fully the cause of refraction. What is a wave front?
4. Why are rays not refracted if they pass from one medium to another of the same density? Why not if they meet a surface at right angles? Are rays bent in passing through one medium?
5. Show how a glass prism refracts light rays.
6. What is a lens? Show how a lens behaves like a prism.
7. What is a plane surface? concave? convex?
8. Name the six shapes of lenses. How does a concavo-convex lens differ from a convexo-concave?
9. Define the principal axis; secondary axis; diameter; optical center.
10. What is the general effect of a convex lens? a concave lens?

11. What is a focus? What is the principal focus?

12. Show how convex lenses bring rays to a focus.

13. In what three ways may light rays enter a lens? In each case where do the refracted rays converge to a focus?

14. In which direction are the rays bent by a convex lens (with reference to the principal axis)? by a concave lens?

15. What is a burning glass? What does it prove?

SECTION VII

REFRACTION; USES OF LENSES

232. Optical Instruments. — Various devices which make use of lenses are called *optical* instruments, because they all have some relation to sight. Both sorts of lenses are used, according to the effect desired; but the most common uses employ the convex variety largely.

We may sum up the more familiar uses of lenses by saying they are employed to form *images*, which shall be *larger*, *smaller*, or *clearer* than the object itself.

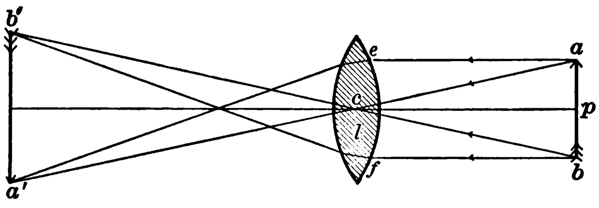

FIG. 165

233. How Images are formed. — Fig. 165 may show how images are formed through a convex lens. Let *ab* be the object and *l* the lens. It must be remembered that *every point of* ab *is sending light rays to every point of* l. Let *ac* be one of these rays: as *c* is the optical

center of *l*, *ac* is the secondary axis, and the ray will not be refracted. Let *ae* be *any other* ray from *a* to the lens: as *ae* cannot be an axis, it will be refracted by *l* and will meet *ac* at some point, *a'*. In the same way draw the axis *bc* and any other ray, as *bf*; they will meet at *b'*.

Now since *ac* and *bc* are *axes*, and *ae* and *bf* are *any other rays* from *a* and *b* to the lens, the points *a'* and *b'* will be the *foci* (plural of focus) of *all* rays from *a* and *b* respectively, which pass through *l*. Similarly, any or all points on *ab* may be brought to a focus back of the lens. Of course *each focus will show the same color and relative position as the point from which the rays came;* that is, *every point* in *a'b'* will look just like the corresponding point in *ab*. Therefore the collection of points *a'b'* will be the *image* of the object *ab*.

234. Focus. — When a lens is used to form an image, it is always desired to have that image formed on a given surface or at some particular point; also the image must be clear and distinct. To get these results, the *distance* from the lens to the given surface must be just great enough so that the rays from the object shall be refracted to a focus *exactly on that surface.* If the distance is not right, the focus will fall in front of or behind the surface, and the image will be blurred.

The distance from the center of a lens to the principal focus is approximately its focal length. *The flatter the surfaces the longer will be this distance.* Rays that are not parallel on entering a lens will be refracted to foci at greater or less distances than the principal focus. The distances of such foci from the lens likewise may vary

with different lenses; but they also vary according as the entering rays converge or diverge more or less (§ 229). Rays from a near-by point diverge more on entering a lens than rays from a point more distant; therefore in forming images (as in photography) *the nearer the object the farther the lens must be moved from the screen.*

235. The Photographic Camera. — The *camera*, shown in diagram in Fig. 166, consists of a light-tight box having at one end a screen or *sensitive plate, a;* opposite is a *convex lens*, *c*, so arranged as to form an image on the plate. A shutter, *e*, keeps light from entering through the lens.

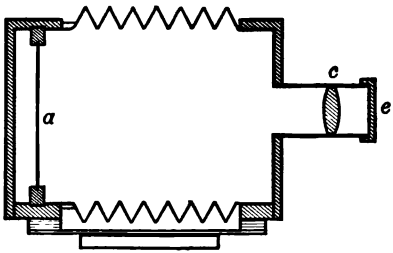

FIG. 166

The lens is moved till its distance from the sensitive plate is correct. Then the shutter *e* is opened, and the light rays are refracted by *c* to a focus on the plate *a*.

On the plate is a chemical mixture, which is so affected by the light waves that an image is formed upon its surface. This image may be brought out (developed) and permanently fixed by a further chemical treatment.

The inside of the camera, as of all optical instruments, is painted dull black to prevent reflection. If the sides were bright in color, any stray beams of light falling on them might be reflected to the plate and blur the image there.

236. The Eye. — This is very much like the camera. Fig. 167 shows a section of the eye, cut across. It consists of a lens for refracting the rays, and a screen on which the images are formed.

The screen is called the *retina;* it covers the entire back of the eye inside, and is composed of very fine nerve endings. *These nerve endings are sensitive to light waves.* They unite to form the *optic nerve, o;* and whatever impression is made by light waves falling upon the nerve endings is sent along this nerve to the brain.

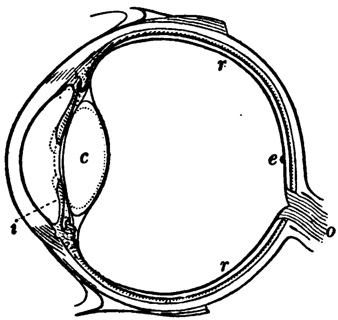

FIG. 167

The lens *c* is called the *crystalline lens.* Unlike the ordinary camera, *c* cannot be moved back and forth; instead, the focal length of the crystalline lens is changed by *altering the shape of the lens.* For near objects the faces of the lens become more convex, and for distant objects flatter. This changing of the lens is called *accommodation;* it is done by the action of several small muscles.

In front of the lens is a round muscle, the *iris, i;* it is the colored portion which we see in the front of the eye. In the center of the iris is an opening, the *pupil,* through which light waves enter the eye. The iris makes this opening larger or smaller to let in more or less rays. Like the camera, the inside of the eye (except the retina) is black.

The image is not equally distinct on all parts of the retina. In fact there is only one small spot, *e*, in the middle of the retina, where the image is entirely clear. On account of this we can see only a small portion of an object distinctly. If we wish to see the whole, our eyes must move about so as to bring rays from all parts to a focus on the spot *e* in quick succession.

237. Eyeglasses and Spectacles. — Glasses are commonly used for all sorts of defects in vision. Near and far sight are common difficulties.

Near sight is a defect in the shape of the eye. *The retina is too far from the lens*, so that the rays from a distant object would come to a focus in front of the retina. *Concave glasses* would cause the rays to diverge before entering the eye, thus making them appear as if they came from a nearer object.

When the retina is too *near* the lens, rays from a near-by object will come to a focus back of it. In such a case distant objects may be clearly seen, while nearer ones will seem blurred. This is called *far sight*. *Convex glasses* will converge the entering rays, making them seem to come from distant objects.

Many other forms of lenses are used as eyeglasses, but these may serve to illustrate their use in general.

238. The Refracting Telescope. — This consists of two lenses mounted at the ends of a long tube. The larger lens (*o*, Fig. 168) is called the *objective*, being nearer the object; the smaller, *e*, is the *eyepiece*, being nearer the eye. (An eyepiece may contain more than one lens.) *The objective serves to collect a great number of rays* and

bring them to a focus inside the tube; this lens does not magnify, it simply collects many rays in order to make a bright image at the focus. *The eyepiece serves to increase the size of the image* and present it to the eye thus magnified.

The magnifying power of a telescope equals the quotient of the focal length of the objective divided by the focal length of the eyepiece. For example, if the focal length of an objective were 10 feet (120 inches) and that of its eyepiece

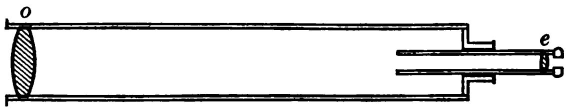

FIG. 168

$\frac{1}{2}$ inch, the magnifying power of the telescope would be ($120 \div \frac{1}{2}$) 240 times.

From this it would seem that any power could be obtained by making an eyepiece of sufficiently small focal length ($\frac{1}{4}$, $\frac{1}{8}$, $\frac{1}{16}$ inch, etc.). This is true; but it is of no advantage to increase magnifying power without using a larger objective, for the supply of light would not be great enough to see clearly. Better a small distinct image than a large one very dim.

Increasing the *diameter* of an objective does not increase magnifying power unless the focal length be greater also. It is of much advantage, however, for larger diameter means that more rays can be collected by the lens, and this gives a much brighter, clearer image.

The spyglass, field glasses, binoculars, opera glasses, and others make use of principles similar to those of the telescope.

Plate V. A Compound Microscope

The *equatorial telescope* is used in astronomical work. Its tube is mounted so that it may be turned by clockwork, at the rate at which the stars seem to move across the sky. Thus it may be pointed at an object in the heavens and remain so all night if desired.

The *reflecting telescope* is a tube with a large *mirror* at the bottom, which catches the rays and reflects them to an eyepiece.

239. The Microscope. — Microscopes are used for enlarging the images of near-by objects which are too *small* to be clearly seen. The telescope is used upon objects too *distant* to be clear.

Microscopes are simple or compound. The *simple microscope* is a single convex lens (Fig. 169).

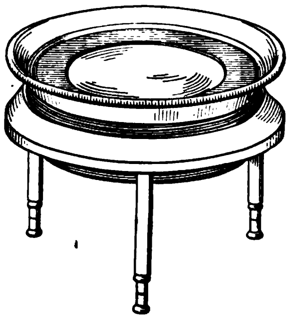

Fig. 169

The *compound microscope* contains two or more lenses. If two, they are placed one at either end of the tube, and are called the "objective" and "eyepiece," as in the telescope. Either the objective or the eyepiece may be made of more than one lens, in which case the group at the object end is called the *objective* and the group next the eye, the *eyepiece*. The *magnifying power* of a compound microscope may be made very great, for each lens increases the already magnified image formed by the lens next below it. For microscopes of high power the object

is placed very near the objective, — one eighth of an inch, and even nearer.

240. How a Convex Lens magnifies. — In the study of convex lenses (§ 229) we learned that rays which converge, on entering a lens, will be refracted to a point nearer the lens than the principal focus (see *f*, Fig. 170). From this it will be easily seen that rays starting from such a point, *f*, *nearer the lens than the principal focus*, will *diverge* on leaving the lens.

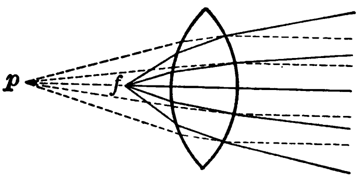

FIG. 170

If, now, an object (*ab*, Fig. 171) be placed in front of a convex lens, nearer than the principal focus, the rays coming from that object will *diverge* when refracted by the lens. Let *ac* and *bd* be two such rays. From the

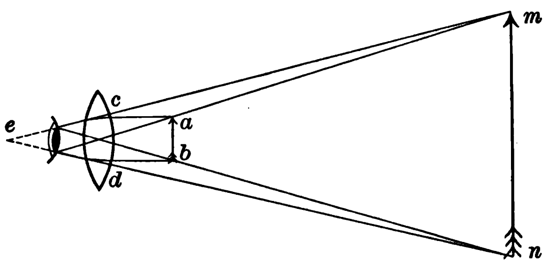

FIG. 171

figure it is clear that *these rays do not diverge so much on leaving as on entering the lens.* Therefore the eye at *e* would see the rays as if they came from a point *m*; that is, the point *a seems* to be at *m*. Similarly, rays

from *b* would seem to come from a point *n*, and all rays between *a* and *b* from points between *m* and *n*. Thus the visual angle *men* is greater than *aeb*, and the object appears to be just that much larger.

QUESTIONS

1. What are optical instruments? Name several.
2. What are the general uses of lenses in optical devices?
3. Explain by diagram the formation of images by a convex lens. Would a concave lens serve any such purpose?
4. Why should an optical instrument be focused? How may this be done? How is it done in the camera? in the eye?
5. What is the focal length of a lens? Upon what does it depend? State the rule.
6. Describe the camera. How are images "taken" by its use?
7. Why are optical instruments painted black inside?
8. Describe the eye. Where is the image formed? Could we see images without the crystalline lens? Could we see light waves?
9. Show how the crystalline lens is focused. What is the use of the iris?
10. How is near sight caused? far sight? How is each remedied?
11. What is the use of the telescope? the microscope?
12. What is the objective? the eyepiece? an equatorial telescope?
13. How is the magnifying power of a telescope found?
14. Explain how images are magnified by use of a convex lens.

SECTION VIII

COLOR

241. Explanation of Color. — We learned in regard to sound waves that, while they all have nearly equal velocity under like conditions, they differ much in vibration rate. This difference in rate of vibration causes

differences in sound which we call "pitch." Now in a similar manner *light waves differ in the number of vibrations per second*, and this gives rise to differences in *color* of rays.

It may be hard at first to get clearly in mind the fact that color is a property of light waves and not of substances. We are accustomed to think of the color of an object, as if the color were a part of it. Now it is of course true that the color of any object depends somewhat on the substance itself; but place some object in yellow light and then in red light, for example, and see if color depends upon the substance *alone*. Every one knows how different a piece of cloth appears by daylight and by lamplight. A bit of thought makes it clear that the color of an object varies with (1) the substance itself and (2) the sort of light waves which fall upon it. Strictly speaking, *color is a property of light waves.*

The color of a light wave depends upon its rate of vibration.

It will help to fix this in mind if we remember that color is to a light wave what pitch is to a sound wave.

242. Number of Colors. — The number of colors is much greater than we can form any idea of; but as in the case of pitch, there is a limit to the power of the eye in detecting them.

Deep red has a relatively low vibration rate, and *violet* a very high rate. Outside these limits, either slower or faster, it is doubtful if many can distinguish colors. And even within these limits we cannot as a rule tell very many shades of color with certainty.

Many persons have a very poor idea of color, being unable to distinguish even the common shades. Such persons are said to be *color-blind.*

243. White Light. — When we speak of *white light* we mean such waves as produce in the eye a sensation called *white. Sunlight* is commonly spoken of as white light.

It has been found that *white light is composed of a mixture of many colors.* Just how many there are cannot be definitely said; the number is surely very great. Of these, however, general divisions seem to be made, so that they may be classed under a few distinct heads. Seven of these general divisions demand our attention because they are clearly different.

244. The Spectrum. — *When light waves suffer refraction, those that have the faster vibration rate are refracted more than those having the slower rate.*

For example: if a beam of light (*ac*, Fig. 172) composed of three colors — red, green, and violet — strike the glass prism at *c*, the rays will be refracted. Of these colors violet has the fastest vibration rate, green next, and red the slowest. Thus the violet rays will be refracted most, the green less, and the red least. The single

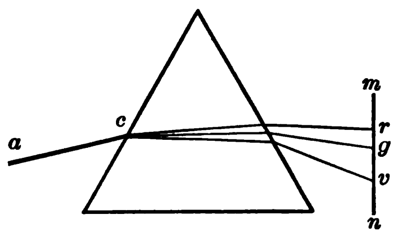

FIG. 172

beam *ac* will be then broken up, all the violet rays going to *v*, all the green to *g*, and all the red to *r*. If the

separated rays fall on a surface, *mn*, we may see the three colors, each in its place ; this would be called a *spectrum*.

A spectrum is formed when light waves are refracted and, the colors being separated, each is sent to a certain place.

245. The Spectrum of White Light. — If white light be refracted and its spectrum formed, we shall find it to be composed of seven distinct shades of color. They are called the *prismatic colors*. Taken in order they are *red*, *orange*, *yellow*, *green*, *blue*, *indigo*, *and violet*.

The spectrum of white light may easily be formed by letting sunlight shine through a piece of cut glass. If we study such a spectrum, we shall find it always arranged in the order just given. It may also be noticed that the colors gradually shade into each other; the orange, for example, is a yellowish red, so that it is hard to tell where the red stops and the orange begins, or the orange stops and the yellow begins.

246. The Rainbow. — Looking at a rainbow we see that it, too, is composed of these same seven colors arranged in the same order. The *rainbow* is simply a spectrum of sunlight which is refracted as it passes through drops of water.

Many summer showers break up rapidly, so that one part of the sky is clear while another part is clouded. The sunlight passes through some thin cloud whose particles of water refract the rays, and the spectrum is formed on other clouds or reflected to the eye.

247. Absorption. — In our study we have learned that opaque bodies may reflect or absorb light waves. When

a body *absorbs* light waves, they seem to stop within it, neither passing through it nor being reflected from its surface. We may define as follows:

Absorption is the taking in of light waves by a body.

248. How Objects are colored. — We know that color depends upon the rate of vibration, that is, the number of vibrations per second in a light wave. But we see about us many objects (*e.g.* a green book, a white paper, a red ribbon), all of them showing some color but none of them luminous and consequently not the *source* of the color vibrations. The question is, How do different bodies, all illuminated with the same white sunlight, show so many different colors?

To understand the answer, it must be kept in mind that when light rays fall upon a body the waves may be (1) *reflected*, (2) *absorbed*, or (3) *may pass through the body without any change.*

If the light be white *sunlight*, then (1) if all the waves be *reflected* from a body, they will come to the eye as white light, and of course the body will seem *white;* (2) if all the rays be *absorbed*, none will come to the eye, and the object will seem *black;* (3) if all the rays *pass through* a body, being neither reflected nor absorbed, the substance is said to be *colorless.* In other words, when white light shines upon an object, it will appear WHITE, *if all the rays are reflected from its surface;* BLACK, *if all the rays are absorbed by it;* and COLORLESS, *if none of the rays are either absorbed or reflected.*

Colored Substances. In addition to those just mentioned, there are many substances which *absorb some*

of the rays and reflect the others. The color of such a substance would then depend upon the rays which it *reflects* to the eye. If, for example, sunlight falls upon a body and all the rays except the red ones are absorbed, the red rays being reflected to the eye make the body seem red. If the green rays alone were reflected, the body would seem green; if the blue rays were reflected and the rest absorbed, it would appear blue.

But in all the cases we have mentioned, the light falling upon the object has been white light. Now we know that things seem colored differently in different lights. In a red light all white objects would seem red; the snow looks blue when seen through blue glasses. A piece of cloth may appear to be of one color in the daylight, and of quite a different color in the evening. The reason for this is simple; for if the color of an object depends upon what waves are reflected to the eye, surely the reflected waves must depend to some extent upon what waves struck the object in the first place. Thus we may say:

The color of any object depends upon (1) what light waves fall upon the object and (2) which of those waves it reflects to the eye.

249. The Sensation of Color. — The manner in which light waves affect the retina to produce the *sensation* of color, is not definitely known. A theory was suggested years ago by Dr. Young, which has since received the support of many prominent scientists, notably Helmholtz.

According to this theory there are *three primary colors*, — *red, green, and violet.* Also there are in the retina

three different sorts of *nerve endings*, one of which is sensitive to red waves, one to green, and one to violet. *White light affects all three sorts of nerve endings, but any of the colors affect them in different degrees.* For example, red waves affect the nerves which are sensitive to red, green waves the nerves that are sensitive to green, etc.

But all other shades of color are supposed to be mixtures of two or all three of the primary colors, and therefore each sort of nerve endings will be affected exactly in proportion to the importance of its color in the mixture. Orange, for example, contains red and green waves, the red being of more importance; in the eye, then, the nerve endings for green and red would be affected, but the red more than the green. Yellow also contains red and green; but in this case the green being of more importance, the nerve endings for green would be affected more than the red. And similarly for all shades of color.

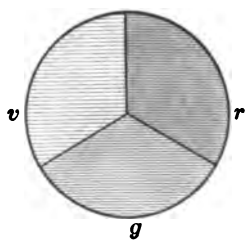

Fig. 173

250. Complementary Colors. — The sensation produced by all the colors of the spectrum together (not separated as they are in the spectrum) is white light. Similarly, the sensation of the three primary colors together is white. If the three are painted on a card (Fig. 173) and the card is rapidly rotated, it appears white.

There are also several *pairs* of colors whose combined sensation is white. Yellow and blue form such a pair; that is, if a card be painted part yellow and part blue

(Fig. 174) and rotated as before, the sensation produced on the retina is white. Two colors whose combined waves produce upon the retina the sensation of white light are called *complementary colors*. Purple and green, red and blue-green, yellow-green and violet are complementary colors.

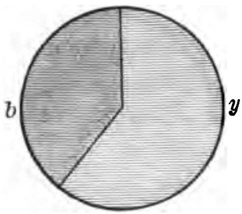

FIG. 174

251. Mixing Pigments. — Note that there is a difference between *combining color sensations* and *mixing pigments* (colored particles).

The rotating card (painted yellow and blue) gives the sensation of white, because it rotates so fast that the rays from the yellow and from the blue fall at practically the same time upon the same spot in the eye. When yellow and blue *pigments* are mixed, however, the small colored particles simply lie side by side, still retaining their individual color. Thus each absorbs part of the spectrum, with the result that only the color not absorbed by either of them (green, in this case) will be reflected to the eye.

252. Colors outside the Common Spectrum. — The spectrum, as human eyes can see it, is bounded by the red and the violet. This is not the limit of the spectrum, however. The waves whose rapidity of vibration would place them beyond the violet end of the visible spectrum are called the *ultra-violet* waves; those whose rate is slower than the red are called *infra-red*. The presence of these waves may be detected by their action on the photographic plate and by other means.

253. The Spectroscope. — It has long been known that *certain metallic substances give a color to a flame in which they are held.* For example: compounds of sodium give a yellow color to flames; potassium compounds color them violet; some copper salts burn with a greenish hue; and compounds of strontium impart a deep red color to flames. It is within a comparatively recent time, however, that this knowledge has developed into a very general practical use; but in that time the *spectroscope* has come to be one of the most important aids to scientific study.

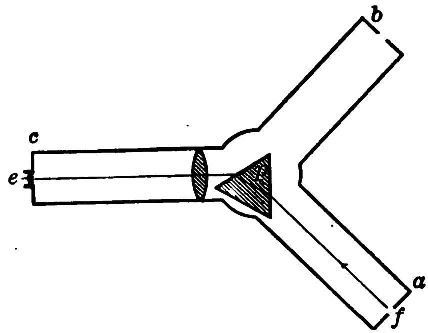

FIG. 175

In its first use the spectroscope was an instrument for separating into their various colors the light rays from a luminous body. Fig. 175 shows in diagram the common form of spectroscope. The glass prism p is placed at the junction of three tubes, a, b, and c. The luminous body is placed at f, so that its rays may pass through a to the prism. The *spectrum* formed as the light waves are scattered at p is viewed through c, a small telescope. The tube b admits white light to the prism; it is not always used.

Now in any flame, f, there may be present some colors which are not prominent enough to be seen with the naked eye. By using the spectroscope *the different*

rays are separated and appear in the spectrum at *p*. The chemist, knowing what color of flame is made by different substances, can (by noting what colors are shown in the spectrum) easily determine what the luminous body contains.

254. Absorption Spectra. — A still more delicate means of recognizing substances is afforded by the *absorption spectrum.* Light waves shining through some substances may be partly absorbed by them; this will cause an appearance of *black bands* across the bright spectrum. Now for different substances these bands may differ in number, width, or position on the spectrum; but for the same substance the bands always appear the same. It is evident, then, that one who knows how the bands should appear for the different substances has a test more definite than that afforded by differences in shades of color.

255. Use of the Spectroscope. — The spectroscope is of great value in analysis of compounds. Its use in astronomy is perhaps most marked. By means of the instrument, light waves may be studied and much may be learned concerning the substances in the sun and stars. Even the motions of distant bodies are studied by changes in the appearance of the spectrum.

QUESTIONS

1. What is meant by color? Upon what does it depend?
2. What is white light? Of what is it composed?
3. Are all colors of light waves equally refracted? Which are refracted most?

4. What is a spectrum? Name the seven principal shades in the spectrum of sunlight. What is a rainbow?

5. What is meant by absorption of light waves?

6. If light waves fall upon a body, what may happen to them?

7. Under what conditions will a body seem white? black? colorless?

8. Upon what two things does the color of an object depend? Would an object which in sunlight seemed blue, for example, really be blue in lamplight, when it seemed to be black? Can any body be said to have a certain color always, regardless of all other conditions?

9. What makes a body look green when white light falls on it? Why does a body look red? blue?

10. State the theory of color sensation. What are the three primary colors? How are all other shades distinguished by the eye? How is the sensation of white produced?

11. What are complementary colors? Is white a color?

12. What colors lie at the ends of the visible spectrum? What are the waves called which vibrate faster than violet? slower than red? How is their existence proved?

13. What is the spectroscope? Name some of its uses.

14. What is an absorption spectrum?

CHAPTER VII

ELECTRICITY

SECTION I

DEFINITIONS

256. Electricity. — It is easily within a hundred years that electricity has been very much studied, and before that time not much was known about it. We read of Franklin, and of how he got a charge of electricity by flying a kite in a thunderstorm. Other men made simple experiments with this unseen power. To them all, however, it was a great but mysterious something; they had little idea of how to control or use it.

Of late years the subject has been very prominent. Scientists have studied it much and applied it in many ways, till to-day it seems like a common thing and we wonder how men lived before its use was known.

257. What is Electricity? — With all their study, however, men have failed to answer the question, What *is* electricity? We cannot say it is matter, for we cannot see that it takes up room. We cannot call it a sensation, as we did sound; nor can we say it is a form of energy, as in the case of heat. No one has ever seen, heard, felt, or tasted *electricity:* we see very

many *effects of electrical action,* very many *results* which follow the presence of electricity, but the thing itself still remains to be discovered.

258. What may be known.—Men have learned a great deal about the subject, but all this knowledge concerns one of these points: (1) *how we may produce electricity;* (2) *how it may be controlled;* and (3) *what are its effects.* We shall have to be content, then, to study these things, and not trouble ourselves too much about what electricity is.

But, even if we do not know just what it is, we often use the word *electricity* just as if it were a substance. We speak of currents of electricity, charges and discharges of electricity, conductors of electricity, etc., just as we would speak about so much matter. Let us understand that this is done simply for convenience: we must have some word by which to express it, even if we do not know exactly what electricity is.

259. How Electricity is made.—Now we do not care much about electricity itself: it is *electrical energy* which is important to us. So what we wish to learn is not really how electricity is made, but rather how electrical energy may be given to a body. We are interested in electricity only so far as it can be made to do work, and we know that it is not electricity but electrical energy which does work. Therefore what we really produce in a body is simply electrical energy.

In the chapter on heat we found that all sorts of energy were so related that any kind could be *transformed* (changed) into any other kind. We cannot

always see just how or why they are transformed, but we can find out the conditions which are necessary to bring about the different changes. Then we have only to *fulfill the conditions and the change will take place.*

Of the different kinds of energy which may be transformed into electrical energy, three are commonly used by man, — heat, chemical energy, and mechanical energy.

To transform *heat* into electrical energy, friction is generally used, that is, rubbing two bodies together. *Chemical energy* is transformed into electrical by means of a cell or battery (a group of cells). Fig. 176 shows a single cell. *Mechanical energy* is usually transformed to electrical by means of a dynamo. We shall study each method with some care.

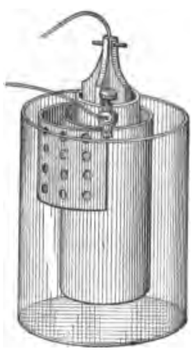

FIG. 176

260. Potential. — It is easy to see that when electrical energy is set up in a body there may be a greater or less amount of it. This possible difference in the electrical state of substances gives rise to what is known as *potential.* Potential may be described as the condition of a body with regard to its ability to give electricity to, or take it from, another body. If one body can give electricity to another, it is said to have the *higher potential:* in the same case the other one would be said to have the *lower potential.*

To distinguish two such bodies, the one having higher potential would be called *positive* or plus (+), the other having a lower potential *negative* or minus (−). When

two bodies of different potential are brought together, *electrical energy flows from the positive to the negative body till both have the same potential.*

The subject of potential will come up again in our study. It is due to potential that electrical energy is able to travel from place to place, and we do not have to be told how very important this is.

It may help some if we compare it with temperature, for potential bears much the same relation to electrical energy that temperature does to heat. We remember that temperature is the condition of a body with regard to its heat. Different conditions are expressed by the terms *higher* or *lower* temperature. Also, when two bodies are brought together, heat flows from the one having the higher temperature to the one having the lower, till both are alike.

Compare this with what we have learned about potential.

QUESTIONS

1. What three general lines of study can we take in regard to electricity?
2. What, in connection with electricity, is important to man?
3. How may any form of energy be produced?
4. What three forms of energy are commonly used in generating electrical energy? By what means is each transformed?
5. What is meant by potential? What names are used to distinguish two sorts of potential? Why is it important?
6. What happens when two bodies of different potential are brought together? In which direction does the flow take place?
7. What important feature of electrical energy is due to potential?
8. In what way does potential resemble temperature?

SECTION II

HOW ELECTRICITY IS CARRIED

261. Conductors. — The great value of electricity to man is due largely to the fact that electrical energy may be carried about and made to do work at a distance from the place where it is produced. Call bells, motors, electric cars, street lamps, and many other devices use electrical energy which has been produced by a battery or a dynamo some distance away. In all these cases it is necessary that something shall travel from the source or *generator* to the place where the electrical energy is used. That which travels thus is called an electric *current.*

It is necessary also that the two points (the source and the point where energy is used) shall be connected by something through which the current may pass easily.

Any substance which transmits an electric current easily is called a conductor.

Perhaps the most common conductor is *copper wire.* All the *metals* (zinc, iron, silver, tin, etc.) are good conductors; also *water*, *earth*, *animal bodies*, etc. Some substances, not usually good conductors, become fairly good when they are *wet;* wood, cotton, and cloth are examples.

262. Resistance. — There is a great difference in conductors. Some carry a current very easily, while others carry it with difficulty, just as sound waves are carried much more easily through one medium than another.

But no conductor is perfect; that is, all conductors offer some *resistance* to the current passing through

them, somewhat as water resists the passage of a vessel through it. Owing to this fact, we find that *whenever a current passes through a conductor, some of its energy is used up in overcoming the resistance offered by the conductor.*

263. Electro-Motive Force. — The flow of the current through a conductor is maintained by the difference in potential between two of its points (§ 260). If one point has a high potential and another point has a low potential, a discharge takes place and the direction of the current is from the higher to the lower potential. If by some means the potential of each point can be kept constant, its charge being renewed as fast as it diminishes, a "steady" current is maintained. It is this difference in potential between points on a conductor that overcomes the resistance offered to the current by the conductor, and it is called by the name *electro-motive force.* The greater the resistance of the conductor, the greater the electro-motive force required to overcome it.

264. Insulators. — We have learned that conductors vary much: there are good ones and poor ones. There are also many substances which are *very bad* conductors; so bad, in fact, that ordinary currents will not pass through them at all. Such substances are called *insulators.* Among the common insulators are *glass*, *rubber*, *silk*, *dry air*, and *cloth.*

The value of insulators in using electricity must be easily seen. If every substance were a good conductor, the electrical energy, as soon as generated, would go out everywhere; not only through its conductors but through

the air, buildings, trees, and anything. We could not keep it where we wanted to, and could have no control over it. As it is, however, a current may travel through a wire conductor because the air is an insulator. If the wire is to cross another wire or enter a building, it is covered with an insulator (rubber, cloth, or glass) at the points where it might touch other things. All wires used in houses, or anywhere that they are likely to be touched by persons or objects, are covered with an insulator. Men working on "live" wires often wear rubber gloves and clothing, or stand on an insulated platform.

QUESTIONS

1. Why is electrical energy so useful as motive power, etc.?

2. What is a conductor? Name some conductors. What is most commonly used? What is the effect of moisture on the conductivity of a body?

3. Do all conductors offer resistance to an electric current? Is the resistance equal in all cases? What do we call a substance which offers great resistance?

4. Define electro-motive force. To what is it due? How does it vary, *i.e.* upon what does it depend?

5. Name some common insulators. Explain their use.

6. Tell which of the following are conductors, and which insulators: earth, air, copper, iron, water, cloth, rubber, lead, paper, wood.

7. Show how insulators are as important as conductors in our uses of electrical energy.

SECTION III

HEAT TRANSFORMED INTO ELECTRICAL ENERGY

265. Static Electricity. — We have learned that heat may be transformed into electrical energy. This goes on quietly oftentimes, and in a way which we cannot wholly understand. The heat in a body is by some means slowly changed into electrical energy, and this energy "stored" in the body may for a long time give no sign of its presence. A body in this condition would be said to be *charged* with electricity. The name *static electricity* is applied to electricity which, being stored up in a body in this way, is *at rest.*

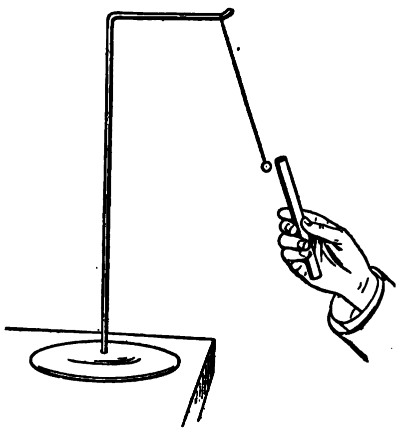

FIG. 177

266. Electricity by Friction. — The way in which men usually generate (produce) this static electricity is by *friction*, — rubbing one surface upon another. Commonly two glass plates are used, but for some simple tests we may use a glass rod rubbed with silk, or a stick of sealing wax rubbed with a woolen cloth.

Hang a ball of elder pith by a silk thread; then rub a glass rod with a piece of silk and bring it near

the pith ball. The ball will be *attracted* to the rod (Fig. 177). Let the ball remain in contact with the rod for a few moments. Soon it will fly quickly off; and after this the rod will *repel* the ball whenever the latter comes near it (Fig. 178). While the ball is still in condition to be repelled by the glass rod, place near it a stick of sealing wax just rubbed with a woolen cloth; the ball will be *attracted* to the stick.

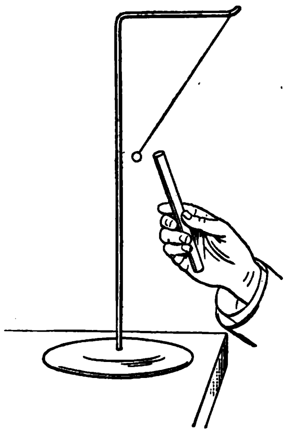

FIG. 178

Now take a fresh pith ball and put the stick of wax near it; the wax attracts the fresh ball, just as the glass rod did. Let the ball touch the wax till it is repelled by it, and then bring the rubbed rod near the wax; the ball which is repelled by the wax is attracted by the glass rod.

Let us note carefully these facts: (1) something was done to the rod and stick of wax when they were rubbed; (2) when either was brought *near* a pith ball it attracted the ball; (3) after *touching* either for a minute, the ball would then be repelled by the one it had touched and attracted by the other one.

267. Two Kinds of Electrification. — To understand more about these things, let us first learn that when the glass rod and stick of sealing wax were rubbed, *charges of electricity* were developed upon the surfaces touched.

In each case, when the pith ball touched the body containing electricity, the ball itself became "charged" with electricity.

But we noticed also that a body charged with electricity from the rod was repelled by the rod and attracted by the charged stick of wax, and that a body charged from the wax was repelled by it and attracted by the glass rod. These facts are explained in this way. When substances are *electrified* (charged with static electricity), ***there are two kinds or conditions of electrification.*** One of these is called *positive* (+) and the other *negative* (–). The glass rod was charged

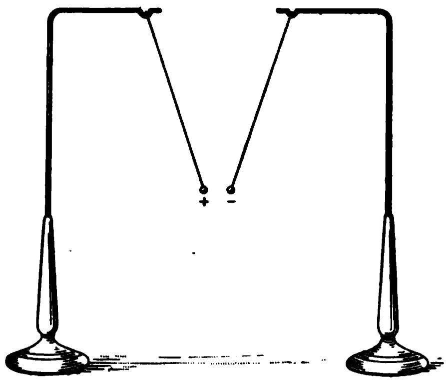

FIG. 179

with the positive sort and the stick of wax with the negative, so that *the ball became charged with the same kind as the electrified body which it touched.*

Going a step farther, and remembering that the rod repelled the ball after a moment, we see that *when two bodies are charged with the same sort of electrification*

they tend to repel each other. But the ball which the rod repelled was attracted by the wax, and the one charged by touching the wax was attracted by the glass rod. So we see *that bodies charged with opposite kinds attract each other.* If we charge the pith balls, one from the glass rod and the other from the wax, they will attract each other when brought together (Fig. 179).

These facts may be summed up in the following statements:

(1) **Some bodies become electrified when they are rubbed;** (2) **when so electrified, some substances receive positive charges, and some negative;** (3) **bodies charged by touching an electrified substance receive the same kind of a charge as the substance they touch;** (4) **bodies charged with like kinds repel each other, and those having unlike kinds attract.**

268. Electrical Discharges. — In studying potential we found that when two bodies of different potential were brought together, electrical energy flowed from the higher to the lower till both had the same potential. In a similar way, when two unlike bodies (+ and −) are brought together a spark may be seen between them, caused by a *discharge* from the positive to the negative. The spark is seen just before the two bodies actually touch.

This may be easily explained. The air is of course an insulator, and it offers *resistance* to the discharge. But the *tendency to flow* is great enough to overcome a small amount of resistance. Thus when the two are so near that there is very little air between them, the discharge takes place. *The passage of the discharge*

against resistance gives rise to heat and causes the air particles to glow.

The sparks seen when we rub a cat's fur are due to discharges. One kind of charge is put into the fur as we rub it, and the other into our hands. As the hand leaves bits of the fur in passing, a discharge takes place between the fur and the hand. The snapping sometimes heard when combing the hair with a rubber comb is due to discharges also.

269. Induction.— Insulators are very bad conductors, — so bad as to be almost perfect *non-conductors;* but in many cases *electricity will act across an insulator*, in one way or another.

We have seen that some bodies may be charged by touching an electrified body. They may also sometimes be charged if they do not actually touch the body which gives the charge, even when there is an insulator between the two. In such a case the body is said to be *charged by induction;* and the part of the insulator between the two, through which the charge passes, is called an *arc.* So we may say a body is charged by *induction* when the electrified body charges the other *across an arc.*

It is important to learn also that when a body is charged by induction, it receives the *opposite kind* from that of the body which is charging it. This may be a part of the reason why a fresh pith ball is attracted both by the glass and the wax. When either the rod or the wax is brought near (but not touching) a pith ball, the ball is charged by induction. This gives it the

opposite kind from that of the body which charged it, and so the two will attract each other. As soon as they touch, however, discharges of the *same kind* flow between them; thus in a moment they are similarly electrified, and so repel each other.

270. Lightning; Explanation. — With these facts in mind we shall find it easy to understand what *lightning* is.

Just how the electrification is brought about, is not clearly understood. It is probable that in some way heat is transformed into electrical energy, but little is really known. We shall have to be content, then, with knowing that *the clouds become charged* with electricity which in some way comes from the atmosphere. This charge may be either positive or negative.

As an electrified cloud passes near to the earth, trees, buildings, water, or the earth itself may be *charged by induction* from the cloud. Thus the earth would receive the *opposite kind* from that of the cloud. Now the cloud may go on storing up more of a charge as it takes in more electricity from the atmosphere, and this of course raises its potential; but as fast as the charge increases, the earth becomes more heavily charged with the other kind by induction, so that the *difference in potential* between the cloud and the earth becomes greater and greater. When finally the difference in potential is great enough to overcome the resistance of the arc between the cloud and the earth, a *discharge* will take place from one to the other. *The passage of this discharge heats the air and causes the spark or flash.*

271. Some Effects. — High points (steeples, towers, trees, etc.) serve often to carry the induced charge as near as possible to the inducing cloud. For this reason they are more liable to be struck. Often the discharge passes from cloud to cloud. This is more common than discharges between earth and cloud.

Heat lightning is the reflection of a flash of lightning which is so far away that we cannot hear the thunder.

Thunder is caused by sound waves which are set in motion as the discharge passes through the air. Exactly how this is done is still a matter of some dispute.

272. Electric Storms. — Lightning usually occurs in connection with the heavy showers of summer. This leads to the idea that the charges of electricity are in some way connected with the enormous amount of heat, which is set free by the sudden condensation of moisture in the warm air.

To understand this, it must be remembered that the warm air of a hot summer day is a drying air; that is, it is able to take in and hold a great quantity of water vapor. As this warm air rises and meets the cold layers above it, the moisture is suddenly changed to liquid (condensed) and falls as rain. The heavy charges of electricity are thought to be due to the energy set free by this sudden condensation, — a simple transformation from heat into electrical energy. The clouds, being moist, are able to store this energy; whereas dry air, being a bad conductor, would not serve to hold it.

273. Positive and Negative Potential. — The terms *positive* and *negative*, as commonly used, are mainly

relative; that is, to say one body is charged positively and another negatively may mean that the first would discharge into the second. It is desirable, however, to sometimes use the terms with reference to some common standard. For this reason men have adopted as a standard the *electrical condition of the earth.* If an electrified body would discharge *into* the earth, it is said to be *positively* charged; if its electrical condition is such that it would receive a discharge *from* the earth, it is said to be *negatively* charged.

This applies to *static* electricity. Care must be taken not to confuse this use of the words *positive* and *negative* with the positive and negative elements in a cell or the poles of a magnet, which we shall consider later on.

QUESTIONS

1. What is meant by static electricity? How is it produced?
2. Show how electricity may be developed by friction.
3. How do two electrically charged bodies act toward each other?
4. What two conditions of electrification are named? How do they affect each other?
5. Under what conditions does a discharge occur? What is meant by a discharge? Why does it cause a spark?
6. When is a body said to be charged by induction? Does a body so charged receive the same or opposite kind of charge as the body which gives it? How is it when they touch?
7. What is an arc?
8. Explain lightning. Why does it occur usually on hot days? Why is the charge stored in the clouds rather than in the air? What causes the flash? Why are high buildings, trees, chimneys, etc., most liable to be struck?
9. What is thunder? heat lightning?
10. By what standard are (+) and (−) electric charges determined?

SECTION IV

CHEMICAL ENERGY TRANSFORMED INTO ELECTRICAL ENERGY

274. The Voltaic Cell.— The device commonly used in transforming chemical energy into electrical energy is called a *voltaic cell.* The principle of this cell is that when two different conducting solids are placed in a liquid (other than a fused metal) a different potential is set up in each. The one having the higher potential is then called *positive*, and the one having the lower potential *negative.*

FIG. 180

If now these two solids are kept apart so that no conductor but the liquid connects them, and are then joined by a conductor outside the liquid, an electric discharge will pass along the conductor from the positive to the negative (Fig. 180). This would, of course, tend to equalize the potentials of the two solids, but the chemical action of the liquid upon them at once renews their difference in potential, so that they are at once in a condition to discharge again. In this way the difference in potential of the two bodies is maintained, and the continuous series of discharges from one to the other constitutes the steady flow or *electric current.*

The two solids are called *plates* or *elements*. Many different substances are used, but in general it is desirable to use two conducting solids in which a great difference in potential will be developed. For the positive plate *carbon* is generally used, though in some cells this element is copper. For the negative plate *zinc* is common, being used in nearly all voltaic cells.

275. Kinds of Cells. — There are many different kinds of cells, according to the use to which they are to be put. In general, if we want a powerful cell to be run for a short time only, we should put *zinc* and *carbon* plates in a solution of *sulphuric acid*. Fig. 181 shows such a cell; it gives a powerful current, but does not last long because the acid destroys the zinc.

FIG. 181

The opposite of this would be the cells used by telegraph systems, where not much current is needed but it is desired to have the cells last a very long time. They use zinc and copper plates and a weak solution of copper sulphate (blue vitriol). Many cells are needed in order to get a strong current, but the only care they need for months is a little water now and then.

276. Gravity Cell. — A cell of this sort (§ 275) is shown in Fig. 182. A large plate of *zinc* is used, being fastened to the top of the glass jar; the *copper* plate rests on the bottom. The weak solution of *copper*

sulphate at the top becomes *zinc sulphate* under action of the zinc, and the copper sulphate in the bottom acts mildly upon the copper. Such a cell is called a *gravity* cell, because the force of gravity keeps the two liquids apart, the copper sulphate being heavier.

277. Grenet Cell. — The cell described above (§ 275) and shown in Fig. 181 is called a *Grenet* cell. The zinc, *a*, is so arranged that it may be drawn up out of the liquid just as soon as the current is no longer needed. Such a cell is very useful in laboratories, where a strong current is needed for a short time only. In an hour or two the zinc would be used up. The gravity cell is much better for constant use; for, though many cells are required, when once started they need very little attention for some time.

FIG. 182

278. Leclanché Cell. — The kind of cell most used in houses for call bells, etc., has *zinc* and *carbon* plates. These are put in a solution of *sal ammoniac*. Such a cell will last for a long time. If not much used it will run for some months, with the addition of a little water now and then to keep it filled. Very little action goes on while the cell is not in use, and so there is almost no wasting of the plates. These cells are common; they

are made and sold under many different names. One of the earlier and better styles is called the *Leclanché* cell.

279. Dry Cells. — Several so-called *dry batteries* are devised. No perfectly *dry* cell can be made, as some moisture is needed to make the chemicals conduct the current. They are, in general, cells containing some moisture but entirely sealed up, so that they are convenient for many uses.

280. Local Action. — It often happens that the metallic elements (particularly the zinc) are full of impurities. If these impurities consist of carbon or some other electro-negative substance, the liquid acting on them and the zinc particles at the same time will cause many small currents to run from particle to particle, thus wearing out the zinc very fast.

This may be prevented by covering the zinc element with mercury. The mercury forms an *amalgam* with the metal, which is the same throughout.

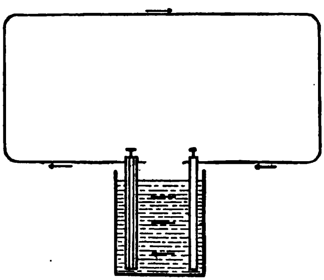

Fig. 183

281. The Circuit. — In order that a current may pass through any conductor, there must be a *complete path* of conductors from the positive element through a conducting body outside the cell to the negative element, then through the liquid to the positive plate again (Fig. 183). This complete path is called the *circuit*.

In order that a current shall flow, the circuit must be complete; that is, there must be no break from beginning to end. When the circuit is not complete it is said to be *open* or *broken*. When a broken circuit is completed it is said to be *closed* or *made*.

This is a matter worthy of our attention, for it is the way in which currents are turned on and off various

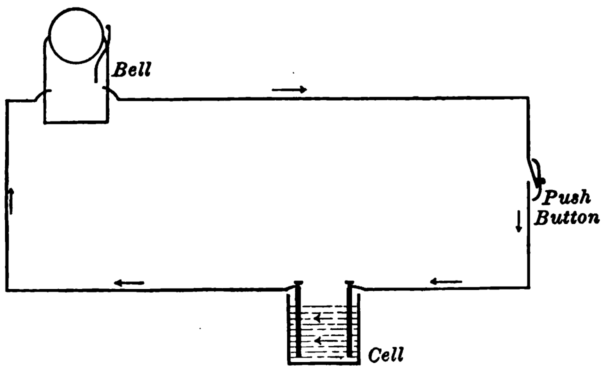

FIG. 184

electrical instruments. When we turn on the electric lights, for example, we simply move a *switch* that *closes a circuit* and allows the current to go through that part of the conductor on which the lamps are arranged. When an operator telegraphs to another, perhaps many miles away, he does so by simply pressing a key which closes a circuit. This allows currents to pass through the key and wire to the other office, and there these currents work a machine according to the will of him who sends the message. Notice that when the circuit is open there is no current in any part of it.

Perhaps the action of a common electric call bell may help us to understand the use and importance of this matter of closed and open circuits. When we want to ring such a bell, we simply push a button. Let us look at Fig. 184 and see what happens. We can follow the circuit from the negative to the positive element in the cell, around through a wire to the bell, then on to the push button and back through the wire to its starting point. The only *break* in this whole circuit is at the button; when we push that, the ends of the wire touch, the circuit is *closed*, and the current flows through the bell, causing it to ring.

Let us note carefully, then, that in order to have a current flow through a conductor there must be a *complete circuit*, and that *the least break in any part of the circuit shuts off the current from every part of the conducting path.*

282. Polarization. — As we shall learn later, the passage of a current through the liquid in a cell breaks up the compound; that is, the water in the cell is slowly decomposed (§ 127) into the two gases, hydrogen and oxygen, of which it is made. The *hydrogen* collects in numerous bubbles around the positive element (Fig. 185); and being a gas (which is of course a non-conductor), it forms quite an obstacle to the passage of the current from the liquid to the positive plate. This is called

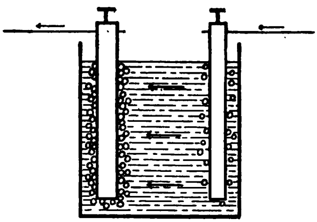

FIG. 185

the *polarization* of the positive element. Clearly this great resistance must use up much of the current and weaken the cell considerably.

To remedy the trouble, different devices are used: one is to add a solution of *potassium bichromate* to the liquid; another is to inclose the positive plate in a *porous cup* and surround it with bits of coke or some oxide. In any case the aim is to provide some substance with which the hydrogen may at once unite, leaving the plate and liquid in contact. Any such substance is called a *depolarizer*.

283. Batteries. — Several cells connected on one circuit compose a *battery*. A single cell is not usually powerful enough to do much work, so two or more cells are united together to furnish the current.

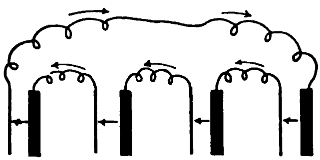

FIG. 186

The cells may be united in one of two ways, — in series or in multiple arc. In *series* arrangement, the positive and negative plates are connected in order, as in Fig. 186. In *multiple arc*, all the positives would be joined together and all the negatives. The instrument, in this case, would be put into the circuit somewhere in the part *abc* (Fig. 187).

284. Difference in Effect.—Series arrangement is used when *great electro-motive force* is wanted. By connecting in multiple arc, we *decrease the resistance offered by the battery* but get no gain of electro-motive force at all.

The electro-motive force of a cell depends upon the difference in potential between its two elements. Thus the electro-motive force of any number of cells arranged in *multiple arc* (Fig. 187) is no greater than that of a single cell. For if the positive in each cell had a potential of 3, for example, and each negative 1, the electro-motive force of one cell would be as 3 : 1 (three to one); if we had three cells, the electro-motive force would be as 9 : 3, that is, (3 : 1) taken three times. But 9 : 3 is the same ratio as 3 : 1; that is, the three positives would still be only three times the potential of the three negatives, just as in one cell the positive was three times the negative. In the same way four, five, or any number would give no increase in *difference of potential* and hence no gain in electro-motive force.

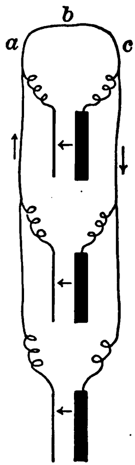

FIG. 187

But as each cell in the *series* (Fig. 186) gets the current at a different stage of its path, its electro-motive force is *added* to that which the current already has; so each cell gives a gain in electro-motive force. In the multiple arc, the current passes through all the cells at the same time.

285. Uses of Battery Currents. — Batteries do not give a powerful current as compared with currents from dynamos, which are used to run cars, lights, and big motors; still they furnish current enough to make them very useful in many ways. Among the common electrical devices which are run by battery currents may

be mentioned call bells, buzzers, spark coils (for firing explosives at a distance, etc.), medical batteries, electric signals, telegraph and telephone systems, and many others.

QUESTIONS

1. What is a cell? Describe a common cell, naming its parts.

2. What substances are used as plates? Could both elements be of the same substance?

3. How is an electrical potential set up in each plate? Why is it different in each?

4. Describe a gravity cell. What is the advantage in using this cell?

5. What is the advantage and disadvantage of a sulphuric acid cell?

6. Describe the sal ammoniac cell. How is it commonly used and why?

7. What is local action? How is it prevented?

8. What is a circuit? What keeps up a current through a circuit?

9. When is a circuit closed or made? open or broken?

10. Does the circuit include the cell? What, in the cell, conducts the current?

11. If a circuit is broken in any one place, is there a current in any part of the circuit? Show the value of this in using electric currents.

12. What is polarization? How may it be prevented?

13. What is a battery? In what two ways may cells be united? What is gained in each case?

14. Name uses of battery currents.

SECTION V

RESISTANCE OF THE CIRCUIT

286. Internal Resistance. — The resistance offered by the liquid in a cell, or by any part of the cell or generator, is called *internal* resistance. It varies with the area of cross section of the path through which the current passes.

The larger the area of cross section of the liquid path the less the internal resistance. The area of cross section of the liquid path would be determined by the area of the smaller of the two elements below the surface of the liquid. Resistance depends also upon the length of the path, but this factor is not so variable as the cross section.

We found that the arrangement of cells in multiple arc decreases the resistance of a battery. Note, in Fig. 187, that the current passes through all the cells at once, thus increasing the area of cross section of the liquid path by every added cell, and consequently *decreasing* the internal resistance.

287. External Resistance. — *External* resistance is that offered by conductors, instruments, and, in fact, all parts of the circuit except the generator. The resistance offered by any conductor depends upon three factors: (1) *the material of which it is made*, (2) *its length*, and (3) *the area of its cross section.*

As to material, of course no rule can be laid down. Some substances are better conductors than others, and

we can tell only by trying them. But when the resistance of any sort of material is once found out, it is put down in a list of *specific resistances* and may always be found by looking at such a list, without actually trying it every time.

With the same substance, resistance depends upon the length and area of cross section.

The longer a conductor, the greater its resistance to a current; that is, if its size be equal at all points. As to the area of cross section:

The smaller the cross section of a conductor, the more resistance it offers. In the case of wires of the same length and material,—the finer the wire, the greater the resistance.

These rules for external resistance should not be hard to remember, as they are really quite what might naturally be expected. As regards the *length* of a conductor, it is a simple matter of reason that a long path should offer more resistance than a shorter one. The farther any force has to act, the greater the amount of energy required, simply because there is more resistance to be overcome. And it is no different when electrical energy has to keep up a current through a conductor: every added length of conductor means more resistance to be overcome.

As to the *area of cross section*, that also is nothing strange. Every one knows that more resistance is offered to the passage of a certain volume of water by a small pipe than by a large one; and while the method of conduction may be different, it is the same general law in regard to the behavior of electric conductors. The larger the path, the less its resistance.

288. Connections. — In practice it is also important to pay careful attention to *connections*. Two excellent conductors may be so badly joined that the resistance at that point more than destroys the effect of their conducting power. In making connections, it is important to scrape the metal to brightness before joining the ends; for almost any metal in time becomes coated with a bit of oxide, through which the current passes with difficulty.

289. Divided Circuits; Shunts. — A circuit may be divided (as at *a* and *b*, Fig. 188) so that a part of the current may pass through one branch (*acb*) and the rest through the other (*adb*). When a circuit is divided, the amount of current passing over each of the branches varies *inversely as their resistances*. In other words:

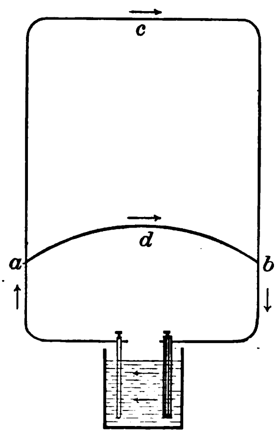

FIG. 188

The less the resistance of each branch the more current it gets. For example, if the path *acb* offers three times as much resistance as *adb*, then the latter, *adb*, will get three times as much current. This is an important principle to remember.

Frequently, in practice, a circuit is tapped in places by short branches, which may carry part of the current to some instruments. These short branches of the main circuit are called *shunts*.

290. Uses of Resistance. — A considerable use is made of the principle of resistance, in helping man to control different instruments which are using electrical currents.

Fig. 189 shows a *resistance box.* The current enters and leaves at p and p'; a, b, and c are switches which rest on metal buttons. These buttons are connected with coils of wire inside the box, which are of different sizes, lengths, and material. By moving the switches to different buttons, one can *add resistance to the circuit* as he wishes.

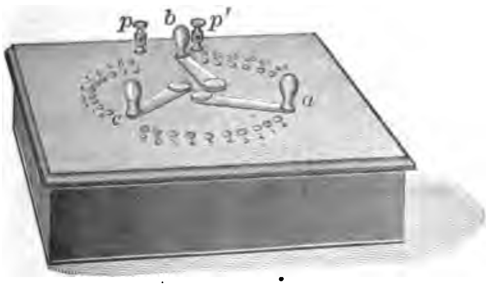

FIG. 189

We have seen that currents may be turned on or off by closing or opening the circuit; in this way we could *start* or *stop* a motor. Sometimes, however, it may be desired to run the motor, but not at the speed which a full current would give to it. In such a case, resistance may be brought into the circuit by means of a resistance box on the same branch with the motor; and because of the increased difficulty, much *less of the current* will pass through that branch to the motor.

291. Fuses. — We have, perhaps, been in a building when suddenly the electric lights went out, or on a

car which stopped short with a dull noise, and left us for a few minutes in darkness. These things are often caused by the burning out of the fuse.

A *fuse* is a short piece of metal which will melt at a low temperature. It is usually put into a circuit just before an instrument or lamp, so that the current must pass through it before going into the instrument. If, now, the current should at any time become so strong that it would injure the instrument, the increased current passing through the fuse against resistance would heat the fuse enough to melt it. This would break the circuit and the instrument would be saved.

QUESTIONS

1. What is internal resistance? Upon what does it depend?
2. What is external resistance? Upon what three factors does it depend?
3. Show how poor connections use up electro-motive force.
4. When a circuit is divided, how does the current divide?
5. What use is made of resistance? Describe the resistance box.
6. What is a fuse? Explain its use.

SECTION VI

ELECTRICAL EFFECTS

292. The Effects classified. — At the present time electricity is used very commonly and in various ways. Many of its uses which seem to produce very different results may be found to depend upon the same principle in the first place, and some uses are entirely

different. In general, all the uses of electricity which are familiar to us are based upon one or another of the four following *electrical effects:* electrolytic, thermal, physiological, magnetic.

293. Electrolytic Effect.—The electrolytic effect may be stated as follows: *A current of electricity has the power to decompose some compound substances on passing through them.* This process is called *electrolysis.*

To explain how it is done, let us decompose some water by electrolysis. Water is a compound substance made of *hydrogen* and *oxygen.* Suppose a conducting circuit to be broken, and two strips of metal, *a* and *b* (Fig. 190), attached to the ends. If, now, these metal pieces (they are called *electrodes*) are put into the water, as in Fig. 190, the current will pass through the water and will decompose it. The oxygen will collect at one electrode and the hydrogen at the other.

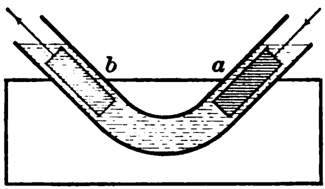

FIG. 190

In the same way many other compound substances may be decomposed, or broken up into their elements. The substance to be thus acted upon by the current is called an *electrolyte.* The electrode through which a current enters the electrolyte is called the *anode,* the one through which it leaves is called the *kathode.*

This process is used by chemists in decomposing substances which are not easily broken up by other means. It is also used in electroplating and electrotyping.

294. Thermal Effect. — We have already seen that when conductors offer great resistance to a current passing through them, they may become heated. It is in this way that fuses are melted (§ 291). This *heating of a conductor* by the passing current is called the *thermal* effect of electricity.

This is one of the effects largely used in electric lights and heaters, electric welding, etc.

295. Physiological Effect. — The effects of electricity upon living bodies are called *physiological* effects. We have perhaps felt a "shock" at some time, as a charge of electricity passed through some part of our bodies. On the same principle is the effect of lightning, which often kills men and animals. If we put two ends of a current-bearing wire on the tongue, we feel a slight stinging sensation as the current passes through; and we know also that if a current were strong enough it might hurt us severely. People are sometimes killed by strong currents of electricity.

Besides these effects, electricity is often used in certain diseases with good results. For this purpose currents from a so-called medical battery are commonly used. These currents are generally weak, being often furnished by a single cell.

The relation of electricity to animal life is a subject which has lately attracted some attention among scientific men. The results of their study are very interesting; and while as yet they are not sufficiently definite to be stated in a book of this sort, we may hope for developments along those lines in the near future.

296. Magnetic Effect. — This is the most peculiar and perhaps the most important of the electrical effects. In a general way, most of us are familiar with it. We have seen and used little horseshoe magnets (Fig. 191), and we know their peculiar power to pick up and hold needles, tacks, etc., by some force which we do not understand. This peculiar power is called *magnetic force.*

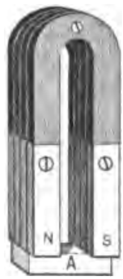

FIG. 191

We know already that a body which exerts magnetic force has the power to *attract* certain other bodies; we shall learn also that it has the power to *repel* some bodies as well.

Any body which has power to exert this magnetic force is said to be *magnetized.* A magnetized body is called a *magnet.*

The use of magnets in electrical devices is very common and important. In general, wherever electrical energy is used to cause motion, it is applied by means of a magnet somewhere in the instrument. Molecular motions and others of minor importance may sometimes be produced as the result of the other effects, but in all cases where the aim is to secure molar motion, magnetic force is employed. Electric motors, bells, clocks, signals, telephones, telegraphs, and other devices make use of this effect; we shall study it more fully in the section on magnets.

But this is not the only magnetic effect of electric currents. All powerful currents (such as are used in electric lights, street cars, and motors) are generated by a *dynamo*, and are a result of magnetic action.

QUESTIONS

1. Name the four common electric effects.
2. What is electrolysis? Explain the process. What is its use?
3. What is the electrolyte? the electrodes? the anode? kathode?
4. What is the thermal effect? How is it used?
5. What is the physiological effect? Name some results of it.
6. Define a magnet. What is the magnetic effect? How do magnetized bodies act toward each other? Give examples.

SECTION VII

MAGNETS

297. The Magnet; Definition. — *A magnet is a body so acted upon electrically that it has the power to exert magnetic force.*

In this study we shall try to learn, first, how magnets may be made; and, second, how they behave after they are made.

298. Two Kinds of Magnets. — There are two general classes of magnets, which differ much in the way in which they are magnetized. They are called *electro-magnets* and *permanent magnets.* The little horseshoe magnets with which we are most familiar are permanent magnets. Electro-magnets are most widely used, however, in electrical instruments; they can be made much more powerful than the other kind.

Permanent magnets are made of *hard steel.* It takes some time to magnetize them, but having been magnetized, they remain so for a long time. That is why they are called permanent.

Electro-magnets are usually made of *soft iron.* They may become magnetized in an instant and lose their magnetism (become *demagnetized*) just as quickly.

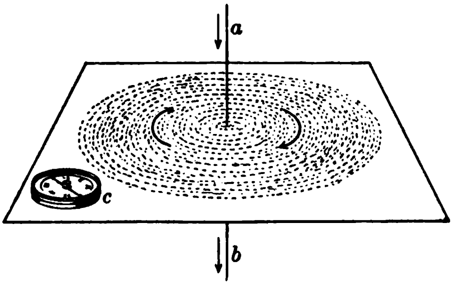

Fig. 192

299. Lines of Magnetic Force.—Two experiments will serve to furnish the first ideas as to how magnets are made.

Strew iron filings on a card and pass a wire, *ab*, through the card, as in Fig. 192. If, now, a current be sent through the wire, the iron filings will move till they form in circles around it, as shown in the figure. This is done by magnetic force, which surrounds the current-bearing wire; the circles show the position of *lines of magnetic force* around the wire. This force may move a compass needle at *c*.

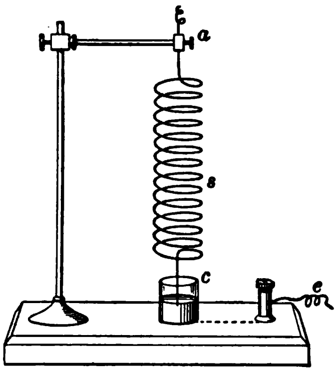

Fig. 193

If, now, we take a coil of wire, *s* (Fig. 193), fasten one end at *a*, dip the other in a cup of mercury, *c*, and connect the cup with the wire *e*, we shall have a conductor from *a* to *e*. Now pass a current through this conductor. As the current goes through the wire, lines of magnetic force go out from all parts of it. Thus each coil of the wire attracts the others, and the end is drawn up out of the cup. As soon as the wire leaves the mercury, the circuit is broken and the coil demagnetized.

From these experiments we learn that a wire through which a current is passing is surrounded by lines of magnetic force, which cease to exist as soon as the current is stopped.

300. Magnetic Field. — The lines of magnetic force around a conducting wire constitute what is known as the *magnetic field*. Whenever any body is near enough to be influenced by the lines of magnetic force surrounding a wire, it is said to be within the magnetic field.

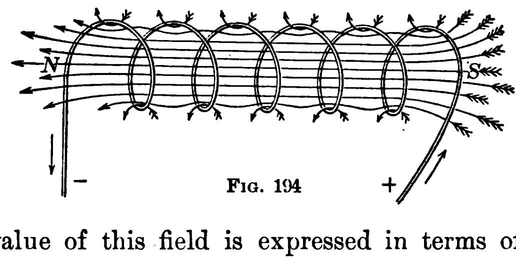

Fig. 194

The value of this field is expressed in terms of "the number of lines of force it contains," and this depends upon the strength of current in the wire. *The greater the current strength in the wire, the greater the number of lines of force in the magnetic field.*

Lines of force surround any magnet, electro or permanent, as they do the wire, and their sphere of influence is likewise called the magnetic field of the magnet.

301. The Solenoid. — If, instead of a single straight piece, the current-bearing wire be bent in the form of a loose coil, as shown in Fig. 194, we have a device called a *solenoid*. The lines of force will extend out from each section of the wire in the direction shown by short curved arrows in the figure. But the turns in the coil of wire being near together, all the different magnetic fields overlap those next to them; and by their action upon each other *all the lines of force within the solenoid are turned in one direction*, as shown by the long arrows.

FIG. 195

302. Electro-Magnets. — If, now, we wind a piece of soft iron with a wire which is covered by an insulator, as in Fig. 195, we find that the ends of the iron have magnetic power, so long as a current is kept going through the wire. The iron serves to collect the lines of force that surround the wire. In this way the iron becomes magnetized; but it is demagnetized as soon as the current stops.

It is in just this way that electro-magnets are made. An *insulated wire* is coiled many times around a piece of *soft iron* (called a *core*). When a current passes through the wire, the soft iron core becomes magnetized, and it loses its magnetism as soon as the current ceases to flow.

Fig. 196 shows an electro-magnet; *b* is the core and *c* the coil of insulated wire. It is easy to see that if the wire were not insulated, the current could enter at *a* and go straight through and out at *e* without going through all the length of the coil.

303. The Electro-Magnet explained. — A moment's thought reveals the fact that an electro-magnet is only *a solenoid bearing a soft iron core.*

The solenoid is merely a coil of wire through which a current is passing; it encloses only a body of air, which is penetrated by the lines of magnetic force around the wire. Now, if a soft iron core is placed within the solenoid, this magnetic force acts upon the molecules of iron, and under its influence the core becomes itself a magnet. The intensity of force of this magnet is greater than that of the solenoid alone. Just what is the nature of the action which the lines of force exert upon the iron core will be explained in connection with the theory of magnetism (§ 308).

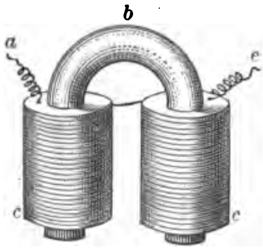

FIG. 196

The value of electro-magnets depends partly upon the fact that *they may be magnetized and demagnetized instantly*, and partly upon the fact that *they can be made very powerful.*

304. Permanent Magnets. — A permanent magnet may be made by drawing a piece of *steel* several times across the end of an electro-magnet, always in the same

direction. The power thus given to the steel may be retained for several years, and can be renewed at any time by the same process.

Permanent magnets are used in many electrical toys. Their more important uses are in small dynamos; many of these are used to make small currents, such as the current for ringing signals in telephone calls; also as "exciters" for large dynamos. They should be kept with care. A blow or heavy jar of any sort may destroy their use as magnets; heating to a dull red will have the same effect.

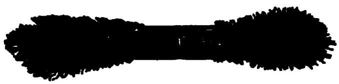

FIG. 197

Two forms of permanent magnets are common, — the *horseshoe* and the *bar magnet.* The latter is simply a straight bar of steel.

305. Magnetic Poles. — If we cover a bar magnet (Fig. 197) with iron filings, we find that they cling very thickly to the *ends*, gradually growing less in number, till near the middle there are none at all. The same would be true of any magnet. Thus we learn that *in any magnet the magnetic force seems to be greatest at the ends and to grow less toward the middle.*

The ends of a magnet, or the points where the force seems to be greatest, are called the *poles* of the magnet.

306. Laws of Attraction and Repulsion. — Take two flat permanent magnets, *c* and *e*, and place them end to end as in (1) (Fig. 198); suppose they *attract* each other. Now turn *e* so that its other pole is toward the same pole of *c*, as in (2); the magnets do not now

attract. Once again, move *c* so that its other pole will be next the magnet *e*, as in (3); this time the poles attract each other again. So we learn that there is a difference between the two poles of a magnet as regards their action.

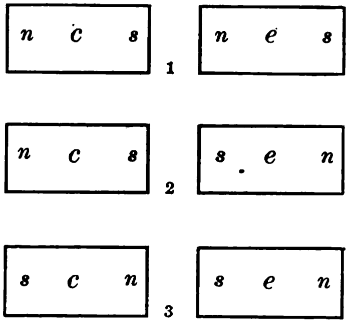

FIG. 198

To find out more about this action, balance a magnetized needle, *ns*, on a point in the middle of a bar magnet, *SN*, so that it will be free to turn from side to side (Fig. 199). The needle takes a position, *ns*, parallel to the bar. Now move the needle till the end *s* is over the pole *S* of the bar, and *n* is over *N*; as soon as we let go, the needle will fly quickly back to its position, *ns*. Further experiments would show that in moving back thus, the pole *n* of the needle was *drawn* by *S* and *pushed* by *N* of the bar, and the pole *s* was pushed by *S* and drawn by *N*.

If, now, we carefully mark the poles *n–s* and *N–S*, hang both the needle and bar so that they are free to swing, and bring one end of a magnet near each in turn, we shall find that the pole which attracts *S* also attracts *s* and repels both *N* and *n*. Thus *s* and *S* are called *like poles*, also *N* and *n*; *s* and *n* or *S* and *N* are called *unlike poles*. Now, recalling the

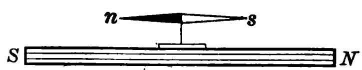

FIG. 199

action of these poles toward each other, we can form the *Law of Magnets:*

Unlike poles attract and like poles repel each other.

This rule is important to learn, for it shows how magnetized bodies act toward each other. In a great number of instruments, however, when magnets are used they act upon bodies which are not magnetized. For this reason it is well to learn also that when any *neutral* (that is, not magnetized) body is acted upon by a magnet, *both poles attract it.*

307. Names of the Poles. — The poles of a magnet are named *positive* (+) and *negative* (–), or *north seeking* and *south seeking.* Sometimes magnets are marked with a line across the positive pole; sometimes the positive pole is marked *N* and the negative *S.*

308. Theory of Magnetism.—An explanation of magnetism suggested by a French scientist, Ampère, more than half a century ago, is generally accepted.

The theory states that magnetism is to some degree a *property of the molecules* of iron. In other words, *every molecule in a piece of iron is an independent magnet,* surrounded by its own lines of magnetic force and having its own + and – poles. Ordinarily these magnetic particles assume any position whatever, the direction of their poles bearing no relation to each other. This idea may be roughly shown by the direction of the arrows in Fig. 200.

Of course, pointing in all directions, these poles neutralize the effect of each other, so that the magnetism of the iron as a whole cannot be detected. But let a

bar of iron be used as the core of a solenoid, all these little magnetic molecules will be acted upon by the stronger lines of force from the wire coil (Fig. 201), and *their lines of magnetic force will all be turned in one direction,* — the same as those of the solenoid. In

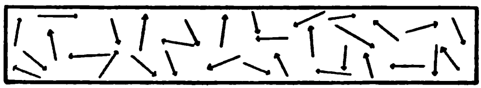

Fig. 200

other words, all the positive poles of the molecular magnets will be turned in one direction, and all the negative poles in the opposite direction; the end of the iron bar toward which the + poles lie will act as the *positive pole* of a magnet, the − poles pointing toward the other, or *negative pole* of the bar. Thus the electro-magnet is made.

309. Explanation of the Two Kinds of Magnets. — The same is true of steel as of iron. Steel is harder than iron, however; and recalling the discussion of "hardness," we know that the molecules of any hard substance will *resist a change of position.* For this

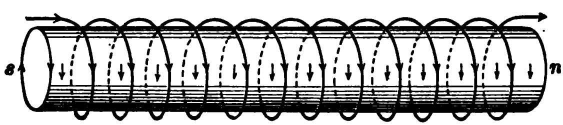

Fig. 201

reason the molecules of *steel* will not be so easily and quickly acted upon by the lines of force from the solenoid; but having been acted upon long enough to have their positions changed, they will not then go back to

their former positions, even after the solenoid is removed. The molecules of *soft iron* will retain their positions only so long as the lines of force from the solenoid are acting. This explains the difference between the permanent (steel) and electro- (iron) magnet.

If instead of placing the steel bar in a solenoid, it is drawn several times across a magnet, the lines of force in the magnetic field act precisely as did those of the solenoid. Thus a common needle may be magnetized by drawing it (always in the same direction) across the field of a small horseshoe magnet.

Heating a body causes motion among its molecules. Thus if a permanent magnet be heated, or if it be subjected to a blow or jar, the molecules may become disarranged, as they were before being magnetized. This explains why heat or jarring spoils a magnet.

310. Explanation of the Poles. — Representing the directions of the molecular poles once again by arrows (as we did in Fig. 200), in a piece of *magnetized* steel or iron the arrows would all point as in Fig. 202;

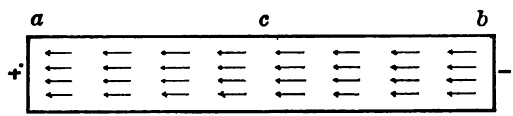

FIG. 202

that is, in a magnet the positive poles of the molecular magnets all point in the same direction, and the negative poles in the opposite direction. Let the arrowheads mark the + poles of the magnetized molecules.

Now it is plain, at a glance, that the end *a* will be a *positive* (+) pole of the bar magnet, having as many lines of force as the sum of all the lines from the positive molecular poles between *a* and *b*. Similarly, *b* will be a *negative* (–) pole, having as many lines of force as the combined number of negative molecular lines between *b* and *a*. From this it is clear that the magnetic force will seem greatest at the poles.

It is also easy to understand why the force should seem to be less toward the middle. Starting from either pole *a* or *b*, the number of lines of force constantly decreases toward the middle, because there will

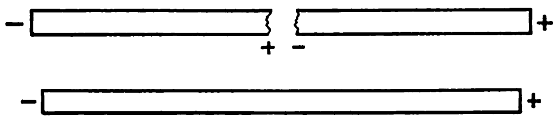

FIG. 203

be fewer molecular magnets between each succeeding point and the other end. At the middle point *c*, the lines of force directed toward the positive end will be just *equal in number* to those pointed toward the negative end; and the two sorts simply *neutralize* each other, destroying their effect. This explains why the middle of a magnet seems to have no magnetic power.

If a permanent bar magnet be broken at some point near the middle, each part will be found to be a magnet with its two poles (Fig. 203); that is, the middle part of the magnet, which a moment before showed no sort of magnetic power, now becomes two poles by the simple act of breaking the bar. This is readily explained by

the theory of magnetism. It illustrates this important fact, that the poles of a magnet are really in *no different condition* from any other part: in all parts the molecular magnetism is the same. *The lines of force are felt more strongly at the poles, because here they are all positive or all negative.* As the middle point is approached from the + pole, the + lines are more and more neutralized by the increasing − lines, till at the middle no force is felt. The same is true of the − end.

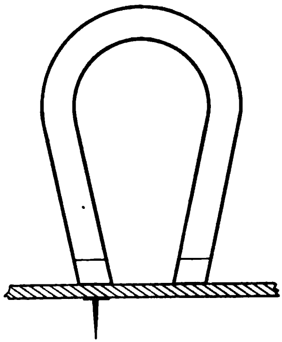

Fig. 204

311. Magnetic Action across an Insulator. — *Magnetic force may act across an insulator,* — in some cases very readily. Iron filings strewn on a card will show the influence of lines of force from a magnet held below the card. Fig. 204 shows a tack held to a piece of glass by force from a magnet above it. Magnets will attract bodies at considerable distances through air, and many other examples might be cited.

Substances through which lines of force may act readily are said to be *magnetically transparent.*

QUESTIONS

1. Name two kinds of magnets. Show the difference.
2. What is the magnetic field? What are lines of magnetic force?
3. What is a solenoid? Why do the lines of force all have the same direction?

4. How is an electro-magnet made? What is the "core"? Why is the magnet stronger than the solenoid in its action?

5. Why is soft iron used as a core? Why is the electro-magnet particularly valuable? Name any uses of electro-magnets.

6. Of what is a permanent magnet made? What is its chief value?

7. What are the poles of a magnet? How are they named?

8. State the Law of Magnets. How do both poles act toward a neutral body?

9. State the theory of magnetism. How does this explain permanent and electro-magnets? What difference between iron and steel is important in this connection?

10. How does the theory explain the "poles"?

11. How may two bar magnets be made from one? How is this explained? Why is there no magnetic force felt at the middle?

12. Do magnets ever act through an insulator?

SECTION VIII

MAGNETISM OF THE EARTH

312. The Earth a Magnet. — We perhaps know a little about the compass and the earth's magnetism, and understand in a general way that something causes the magnetized needle to point north. But we wonder why it is so.

The answer is simply that *the earth is a big magnet;* and, being a magnet, it of course has its positive and negative poles, which attract and repel just as do other *magnetic poles.* Just why the earth is a magnet we cannot say; suffice it to learn that it is so, and to understand its use to man.

313. The Dipping Needle. — The fact that the earth is a magnet may be shown by using a *dipping needle.*

This is simply a magnetized needle, hung so that it is free to move up and down.

Fig. 205 shows five positions of a dipping needle placed on a bar magnet. Notice that at the middle of the magnet the needle is horizontal; as it moves toward the + pole of the magnet, the − pole of the needle goes down, and as it moves toward the − pole of the bar, the + pole of the needle gradually goes down.

Experimenting with the dipping needle, a point may be found, near the earth's equator, at which the needle will assume a horizontal position. As we go *north* from

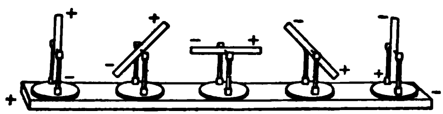

FIG. 205

this point, the + pole of the needle gradually moves downward, till we reach a point at which the needle will be vertical, with its *positive pole* down. Starting *southward* from the same point, the *negative pole* would gradually go down, till we come to a place where it would point straight downward. This shows that near the equator the earth's magnetism is neutral, and it increases in strength as we move north or south.

The place at which the positive pole of the needle points straight down is called the *negative magnetic pole* of the earth. It is not the north geographical pole; in fact it is some distance away. But the magnetic pole is in a general northerly direction from us, and we commonly think of it as "north."

314. The Compass. — The *compass* is a *magnetized needle* placed upon a vertical pin so that it is free to turn horizontally with ease. Being small and easily moved, the poles of the needle will be affected by the magnetic poles of the earth; and, no matter where a compass may be, its needle will always point in a line to the magnetic poles of the earth.

The compass is of great help to man in traveling through places where there is nothing else to guide him. Sailors in particular depend upon it. Many times when at sea, with clouds covering the sun and stars, the compass gives a man the only idea he has of his direction. Fig. 206 shows a common compass.

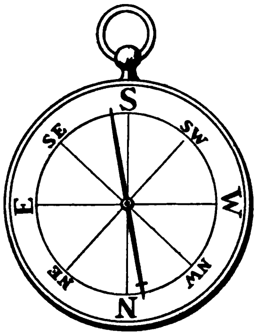

FIG. 206

315. The Angle of Declination. — The *north magnetic pole* is almost twenty degrees lower latitude than the geographical pole. It is northwest of Hudson Bay, and is slowly moving westward at present. At some points in the United States a straight line to the north pole would pass through the magnetic pole also; of course the compass needle would point to the true north in such places. But elsewhere it is evident that the compass does not show the *true north;* it points always to the magnetic pole. The angle between the meridian of a place and the direction of the compass needle at that point, is called the *angle of declination.*

For different places on land or sea this angle is recorded on charts. Any one desiring to know the true north must consult a chart and add this angle to the reading of his compass.

QUESTIONS

1. How is the magnetism of the earth shown by a dipping needle? Where are the magnetic poles of the earth?
2. What is a compass? Does it point true north?
3. What is the angle of declination?
4. Of what use is the compass to man?
5. Could any point be found where the needle would point south? west? east?
6. What must be known in order to use the compass at any particular place?

SECTION IX

ELECTRIC CURRENTS BY INDUCTION

316. The Principle. — Some time ago we learned that electrical energy is usually generated by transforming heat, chemical energy, or mechanical energy. It is by this last means that all the most powerful currents are made, so it is well to understand how it is done.

If we place a card upon the ends of any magnet, and cover the card with iron filings, the filings will move and arrange themselves as in Fig. 207. This shows that lines of force radiate from the poles of a magnet, just as they did from the current-bearing wire. Now the *principle* which is used in generating currents is this:

If an unbroken wire conductor be moved so as to cut lines of magnetic force, an electro-motive force will be set up in the wire which will cause a current to pass through it.

317. The Dynamo. — The instrument used for transforming mechanical energy into electrical energy is called a *dynamo*. It works upon the principle just given (§ 316), that a *current* is set up in a wire which is moving so as to cut lines of magnetic force. Therefore a dynamo is made of a *magnet*, with a *coil of wire* so arranged as to move across its lines of force.

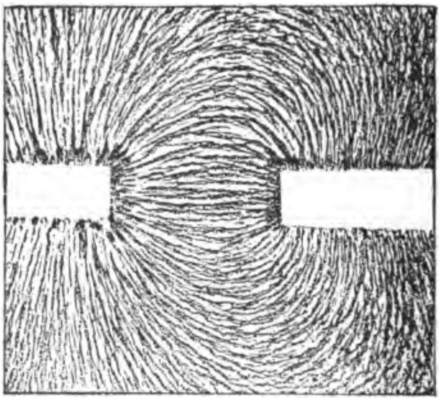

FIG. 207

Fig. 208 may help to show this. In the figure *m* is an electro-magnet, of which *p* and *p'* are the poles. The coil of wire *a* is so fixed as to turn freely about the axle *e* in the direction shown by arrows. *As the coil is turned, the wires cut the lines of magnetic force between the poles* p *and* p', *and a current is generated in the coil of wire.* This current passes out from the coil into the circuit *c* by means of two *brushes*, *b*, which touch the ends of the wire coil.

The coil of wire which turns is called an *armature.* It is usually turned by means of a steam engine, with which it is connected by a belt on its axle. The steam engine furnishes the mechanical energy, and it is changed into electrical energy in the dynamo. Of course other sources of power may be used besides steam. Some small dynamos are worked by hand, as in the telephone. Water power is now commonly used for this purpose;

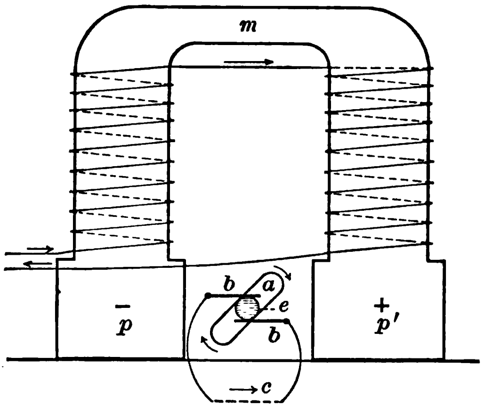

FIG. 208

and in some cases large power houses are built near a river or water fall (as at Niagara), the current being conducted for many miles and used in a distant city.

318. Permanent-Magnet Dynamos. — The magnets may be permánent magnets or electro-magnets. *Permanent magnets* are used in small dynamos, where weak currents are desired. They sometimes serve as exciters for large dynamos. Fig. 209 shows a permanent-magnet dynamo, such as is used in telephones.

The magnet in this sort of dynamo is of course always magnetized, so that a current may be generated any time by simply turning the armature. This is often done by hand.

319. Electro-Magnet Dynamos. — The current for the coils of an *electro-magnet* machine may be supplied in three ways: (1) from some other dynamo — this sort is called a *separately-excited* machine; (2) part of the current made by the dynamo is used to excite the magnet — this is said to be *shunt wound;* (3) all the current is sent through the coils of the magnet before going out into the external circuit — this is said to be *wound in series.*

FIG. 209

In the last two types it is evident that there is no current in the coils except when the dynamo is working. Therefore to start such a machine, a current must first be sent through the coils of its magnets. When a machine is in daily use, generally its iron cores will retain enough lines of force to start a weak current when the armature is turned. This weak current, passing through the coils, adds to the number of lines of force in the cores of the magnets, which in turn adds to the strength of current generated; and so in a few moments the dynamo is running regularly at its best.

More often, perhaps, such machines are started by a current from another dynamo (as in the separately-excited type), which may be disconnected as soon as

the dynamo is running. The *exciter* which is used in this case and for the separately-excited machines, is a small dynamo which has already been mentioned (§ 318).

320. The Alternating Current. — The *direction of the current* through a wire depends upon *the direction in which the wire is moving across the lines of force.* In Fig. 210 the direction of lines of force in the magnetic field is shown by dotted parallel lines; the coil of wire *ab*, which acts as an armature, is moving as shown by the curved arrow. As the portion of wire *a* moves

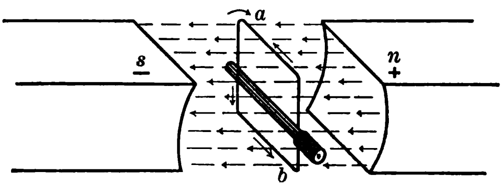

FIG. 210

downward, the current passes through it as the straight arrow indicates; but when it arrives at the position *b* and starts to move *upward* through the field, then the current flows through the wire *a*, *in the opposite direction*, as shown by the arrow at *b*.

Thus it may be seen that the current taken off the armature by the brushes will flow through the circuit, first in one direction and then in the opposite. Such a current is said to *alternate.* A dynamo which gives forth a current of this sort is called an *alternating-current dynamo*, or an *alternator.*

321. The Direct Current; Commutators. — For many purposes it is desirable to generate a current which shall

flow always in one direction,—a *direct* current, so called. A dynamo may be made to give a direct current by a simple device called a *commutator*.

Fig. 211 shows the simplest sort of an armature (one coil) and the commutator. In the figure, *ab* is the coil of wire serving as an armature. Attached to the axle is a metal ring, *cc'*, divided into two segments, each of which is insulated from the other and from the axle; the coil of wire is attached to this ring, one end to the segment *c'* and the other end to *c*.

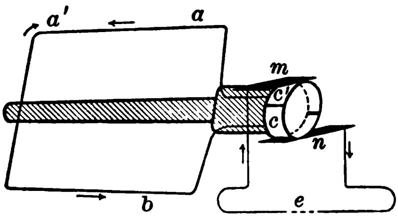

FIG. 211

Now, as the armature turns, a current is generated, which moves through the wire coil as shown by the straight arrows. This current goes from the section *b* into the part *c* of the ring; thence into the brush *n*, through the external circuit *e*, back to brush *m*, to the part *c'*, and out into the armature coil at *a*. After a half turn, however, the section *a* will be in the position which *b* occupies in the figure, and *the direction of the current through the wire will be reversed;* that is, instead of flowing from *a* toward *a'* it will flow from *a'* toward *a*. But if *a* will be in the position of *b*, the segment *c'* will also be where *c* is in the figure. Thus when the direction of flow becomes turned toward *a*, the current will pass on into *c'*; and as *c'* will then be resting on the brush *n*, the outgoing current will continue to pass through *e* *in the same direction* as before. No matter

PLATE VI. AN ALTERNATING-CURRENT DYNAMO

which section of the armature coil is in the lower part of the field, its corresponding segment of the commutator will be resting on the brush n; and as the flow in this lower section will be *toward* the ring always, the brush n will always get the outgoing current.

A generator provided with a commutator is called a *direct-current dynamo.*

322. Dynamo Currents. — The current generated by a dynamo is used in many ways. In all larger towns and cities there are power houses where dynamos are always kept running; the current is sent in *mains* all over the city and is used for different purposes. The currents used by motors, electric lights, street cars, electric furnaces, etc., are dynamo currents.

The alternating-current machine has come to be very widely employed. Plate VI shows a view of one of these big alternators.

323. Magnetic Induction. — In connection with static electricity we found that one body could be electrified by another, across an insulator. We now have another case which is very similar, for the current generated in the moving wire is the direct result of *magnetic force acting through an insulator.* This phenomenon may be called *magnetic induction.* It was extensively studied by Michael Faraday, a noted English scientist, who made many valuable contributions to our knowledge concerning electrical effects.

324. The Induction Coil. — Somewhat similar to the dynamo in its action, the *induction coil* differs in this respect, — that it is not used to generate currents, its

general effect being to *modify* currents already made, and adapt them to certain purposes.

In its simplest form, an induction coil consists of two coils of insulated wire so arranged that one may fit into the other. One of these coils (*a*, Fig. 212) is connected with a battery; this one is called the *primary coil.* The other may be in circuit with any device through which the modified current is to pass; it is called the *secondary coil.* The secondary coil is in a certain sense similar to the armature of a dynamo; it is the place in which the changed current is to be formed (*b*, Fig. 212).

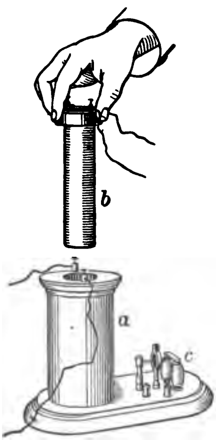

FIG. 212

It matters not which coil is placed within the other. The primary bears the current which is to be changed, and the secondary bears the changed current.

325. The Action of the Induction Coil. — It must be carefully noted that if the primary coil be placed within the secondary and a steady current flow through the primary, there will be no induced current in the secondary. The important feature is not that the coil of wire shall cut the lines of force which surround the primary, but that there shall be some *change* in those lines. The principle of the induction coil may be stated as follows:

A current is set up in the secondary circuit when there is some change in the number of lines of force which the secondary cuts.

This necessary change in the number of lines of force cut by the secondary coil is brought about in three ways.

(1) *The primary may be put into or removed from the secondary.* While the primary is moving, its lines of force are being cut by the secondary coil; but the induced current in the latter stops as soon as the motion ceases.

(2) *The strength of current in the primary may be rapidly increased or decreased.* Changing the current strength of course changes the number of lines of force; but in this case also the induced current lasts only while the change is being made.

(3) *The current in the primary may be rapidly made and broken.* The part *c* in Fig. 212 is a device for performing this; it is called a "make-and-break piece."

The third method is the one which is most generally used, because the making and breaking may be accomplished at a much faster rate than in the others.

In connection with these methods it may be noted that the primary coil is a solenoid; therefore a soft iron core inserted within it would alter the effectiveness of the coil, much as it made of the solenoid a more powerful magnet. Instead of the primary coil a permanent magnet could be used in (1).

326. Direction of Current. — The direction of the induced current depends upon the direction of the change which caused it. Making the circuit, strengthening the primary current, and putting the primary into the secondary, all produce a current in one direction; breaking the circuit, weakening the primary current, and removing

the primary coil, all produce a current in the opposite direction. Hence it is evident that *the current induced in the secondary coil is an alternating current.*

327. Use of the Induction Coil. — The primary coil is usually of short, coarse wire, and the secondary of long, fine wire; that is, the primary offers little resistance and the secondary great resistance to the flow. The value of the instrument depends upon the fact that when a current of some *strength* but low potential flows through the primary coil, the current induced in the secondary will have little strength but a *high potential*, — that is, great electro-motive force. Therefore the *induction coil* may be considered as *a device for obtaining an alternating current of high potential from a strong current of low potential.* By its aid, the current from a single cell may be utilized and made to do a considerable piece of work. The coil is an important factor in the so-called *medical battery*, a device employed to send an alternating current through various parts of the human body in treatment of disease.

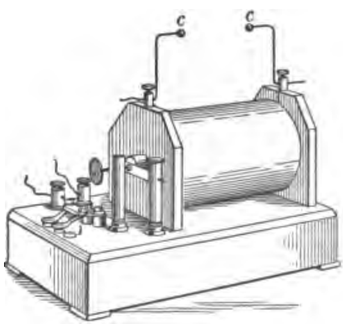

Fig. 213

Fig. 213 shows an induction coil used as a *spark coil.* The alternating current from the secondary is made to leap across the space *cc*; and this being filled with air, the current meets high resistance and causes a spark.

Of course the *arc cc* could be at a greater distance from the coil if desired. Spark coils similar to this are used in forming a spark for many purposes, such as firing heavy explosives, lighting gas jets, exploding gas in gasoline engines, etc.

328. The Transformer. — It will be remembered that the induction coil has a short, coarse wire in the primary

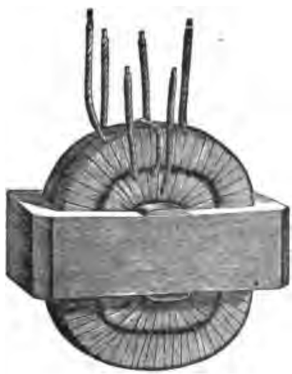

FIG. 214

FIG. 215

and a long, fine wire in the secondary circuit; also that the coil gives a weak current of high potential, in place of a strong current of low potential. If, instead of this arrangement, the primary be made of long, fine wire and the secondary of short, coarse wire, the result will be just opposite; that is, *a weak current of high potential may be changed into one of great strength and low potential.* This latter arrangement of the coils constitutes a device called a *transformer.*

Fig. 214 shows the arrangement of coils. Both are wound around an iron ring or core. There is no make-and-break piece used, because the current in the primary is taken from an alternating-current dynamo.

Fig. 215 shows the outside of a transformer, — a familiar object wherever electric mains are much in evidence. In order to traverse the comparatively small copper wires which conduct the current over long distances, a *very high potential* must be generated by the dynamo. Such a current would be a source of danger if allowed to run into houses or shops where all sorts of people might use it. Therefore each house using the current would have a transformer; the high-potential current in the main would then flow through the primary coil, and a current of greater strength but lower potential would be induced in the secondary. This *induced current* would be conducted into the building and there used — for electric lighting mostly.

The current from a transformer is of course alternating. For incandescent lights this does not make any difference, however; for the alternations, occurring about one hundred every second, allow no time for the filaments in the lamps to cool in the least between currents.

QUESTIONS

1. Upon what principle may mechanical energy be transformed into electrical energy?

2. What is a dynamo? What are its important parts? What sort of magnets are used for powerful currents? By what forces may a dynamo be run, and how?

3. In what three ways are dynamos wound? Describe each.

4. From what source does a separately-excited machine get its current? How are shunt and series dynamos started?

5. What is a direct current? an alternating current? Which would a dynamo ordinarily make?

6. What is a commutator? Explain its working.

7. For what are dynamo currents used? Explain the advantage and the use of permanent magnets in dynamos.

8. What is meant by magnetic induction?

9. Describe an induction coil. What is its use?

10. Explain the action of the induction coil. Which is the primary coil? the secondary? Of what sort of wire is each made?

11. In what three ways may the current in the primary be changed? Which is most used? What sort of a current will be set up in the secondary? What is a spark coil?

12. What is a transformer? How is it constructed? For what is it used? What sort of a dynamo current does a transformer use? What sort does it give off?

SECTION X

ELECTRICAL MEASUREMENTS

329. Current Strength. — The expression "current strength" does not imply the ability of the current to cause motion nor to overcome resistance; it refers rather to the magnitude of the current, as measured by its effects. Perhaps, in order to get a clear idea of its meaning, we can do no better than to call it the *rate of flow* of the current; that is, the amount of electricity which would be transferred by it in a unit of time.

The unit employed in measuring current strength is the *ampère*. The *standard ampère* is the current which, in decomposing a solution of silver nitrate, will deposit silver at the rate of 0.001118 grams per second.

330. Quantity of Electricity. — The quantity of electricity carried by a conductor is expressed in terms of *coulombs.* The *unit coulomb* is the quantity of electricity transferred by a current of one ampère in one second. From this it may be seen that the ampère is the current strength which could transfer one coulomb per second.

331. Resistance. — The unit of resistance is called the *ohm.* The *standard ohm* is the resistance offered to a steady current by a column of mercury 106.3 centimeters long, weighing 14.421 grams, and of constant cross-sectional area, at 0° C.

332. Electro-Motive Force (E.M.F.). — It has already been shown that electro-motive force serves to maintain the current against the resistance of a conducting body. Care must be used to distinguish this from current strength; the latter is rather a measure of magnitude — it gives no idea of ability to do work or to travel over a conductor. The two are quite different: we have already seen that a current may have great strength and little electro-motive force, and *vice versa.* A certain relation does exist, as we shall see, between electromotive force, current strength, and resistance; but it is important to keep each clearly in mind, giving to E.M.F. the function of transferring electricity.

The measure of electro-motive force is the *volt.* A volt is the E.M.F. required to keep up a current of one ampère against a resistance of one ohm.

333. Electrical Power. — The measure of electrical power, or the rate at which work is done by a current, is expressed in terms of *watts.* The unit watt is the rate

at which work is done by a current of one ampère flowing between two points on a conductor, whose difference in potential is one volt.

334. Ohm's Law. — It has been seen that the induction coil gives a current of high E.M.F. and little strength, for one of low E.M.F. and greater strength. Also that the transformer changes a weak current of high potential into a strong current of low potential. These changes depend upon the *relative resistances* of the primary and secondary coils in each case. Thus there seems to be some relation between current strength, electro-motive force, and resistance. This relation has been studied and determined. The result is the following statement, called *Ohm's Law* after the German scientist of that name.

The strength of current is equal to the electro-motive force divided by the resistance. The law is expressed in a formula, as follows:

$$C = \frac{E}{R},$$

from which we may easily derive

$$E = R\,C, \text{ and } R = \frac{E}{C}.$$

QUESTIONS

1. What is meant by current strength? What is the unit?
2. What is the unit of quantity of electricity? of resistance? of E.M.F.? of power?
3. How much is one coulomb? one ohm? one volt? one watt?
4. Carefully show the difference between the strength and the electro-motive force of a current. Which keeps the current going?
5. State Ohm's Law.

SECTION XI

SOME ELECTRICAL USES

335. Motors. — Whenever electrical energy is used to do very heavy work, as in running machinery, cars, etc., it is applied by means of a motor. Motors depend upon the *magnetic effect* of electric currents.

A *motor* is made very much like a dynamo; but instead of turning the armature by means of an engine, a strong current from a dynamo is sent through its coils. This makes an electro-magnet of the armature, so that it has poles like any magnet. *The magnetic action between the poles of the armature and those of the magnet causes the armature to turn.* If, now, a belt be put on the turning axle, the motor may be made to run machinery.

336. The Motor explained. — Fig. 216 may serve to explain the action of the motor. In the figure, *ab* is the armature, which is to revolve between the poles (+ and –) of the magnet. The current is supplied to the coil of the armature, *ab*, through the commutator *c*. Now suppose the current to pass through the brush *m* to the upper half of the broken ring *c*, and thence through the coil *ab*, as the arrows indicate; the coil will become an electro-magnet, of which the section *a* is the

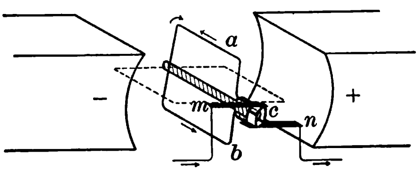

FIG. 216

negative and b the positive pole. In this condition the + and − poles of the magnet will attract the − and + poles of the armature, respectively; also the two + poles will repel each other, as will the two − poles. The four combined forces tend to turn the armature as shown by the curved arrow.

As soon as ab crosses the horizontal position (see dotted lines), the other half of the commutator will touch the brush m; the current will thus pass first into the portion b, making that the − pole and a the + pole. But as b is now above and a below the horizontal plane, the − and + poles are still in a position to be attracted and repelled *in the same direction* as before. Thus, by means of a commutator, the poles of the armature are kept in such a position relative to those of the magnet that the motion shall be always in the same direction.

This description is based upon a machine using a direct current. The construction of motors using an alternating current is increasingly common. In such cases no commutator is needed.

337. Electric Cars. — Fig. 217 shows how electrical energy may be used to run street cars. A dynamo current passes through the wire *w*. From this it is conducted through the *trolley*, *t*, to the top of the car; then by wires through the *controller*, *s*, and to the *motor*, *m*, under the car. After passing through the motor, the current goes through the wheels and rails back to the power house, thus completing the circuit.

The motor is connected with the axle of one set of wheels; and, as its armature turns, the wheels revolve

and the car is thus driven. The speed of the car may be governed by a man at the controller *s*. By moving the switch so as to throw more or less resistance into the circuit, the current passing to the motor may be made weaker or stronger; then, of course, the greater the current the greater the speed of the motor and car.

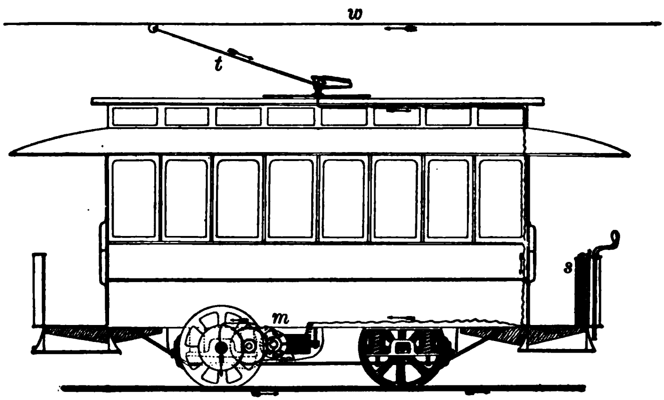

FIG. 217

338. The Electric Call Bell. — This depends upon the magnetic effect of an electric current. To run a simple call bell, a battery of two cells is usually enough. We are familiar with the buzzing sound of these bells; a study of Fig. 218 will show how it is made.

In the figure, *m* is an *electro-magnet* and *s* is a *spring* which holds the hammer that hits the bell. Now follow the circuit carefully through the wires, magnet, and part of the hammer spring. When the circuit is closed (by pressing a button, as we have learned before, § 281), a current going through the wire *magnetizes* the

electro-magnet *m*. The magnet then draws the hammer quickly, and the ball on its end hits the bell once. But as soon as the hammer is drawn to the magnet, the part *a* leaves the point *c* and the circuit is broken. This *demagnetizes* *m*, and the spring *s* makes the hammer fly back again. At once *a* touches *c*, the circuit is again closed, *m* is again magnetized, and the hammer is drawn a second time. This thing is repeated just as long as

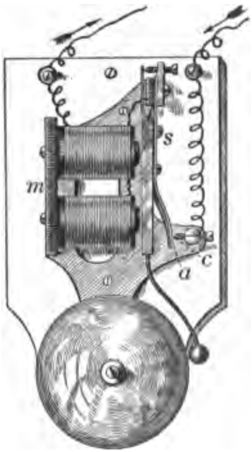

FIG. 218

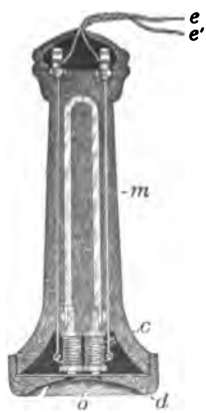

FIG. 219

the circuit is closed at the button, and it happens so rapidly that the blows upon the bell are near together, giving their buzzing sound.

339. The Telephone. — Another device which makes use of the magnetic effect is the telephone. Fig. 219 is a view of the inside of a telephone *receiver*, but it will serve as well to show how the instrument into which we talk is arranged.

In the figure, m is a *permanent magnet;* d is a *disk* of metal which is very near the end of the magnet but does not touch it; c is a coil of wire wound around the end of the magnet and leading out into the circuit through the wires e and e'.

As we talk into the opening o, the sound waves strike the disk d and cause it to vibrate. Of course in vibrating it moves back and forth in front of the magnet, going near to it and then springing back from it very rapidly. In this way *stronger and weaker currents are sent quickly through the coil* c and out through the wire.

Fig. 220 will help show how these currents act in telephoning. Suppose you are talking at the end A to some one at B. The sound waves from your voice cause the disk d to vibrate exactly as they are vibrating. Now as d, in vibrating, moves toward m, a current is set up in the coil; this current travels to the coil at B, strengthens the magnet there, and draws that disk toward that magnet. In the same way, when your disk flies back from

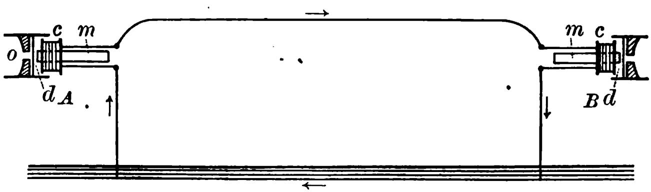

FIG. 220

the magnet, the disk at B will fly back. Thus the disk at B does just what the disk at A does; and if the disk at A is vibrating just like your voice, that at B will so vibrate. *The vibration of that disk will cause sound*

waves, which will travel through the air to the listener's ear. These waves will be weak, but can be heard if his ear is close to the disk.

Note that currents of electricity travel over the wire, not sound waves. A battery is put into the circuit to

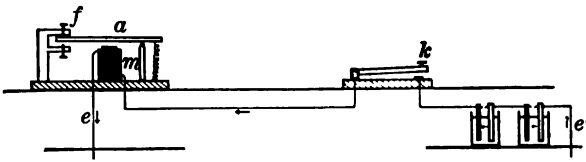

FIG. 221

overcome the resistance of the wire. The earth is used instead of a return wire to complete the circuit.

340. The Telegraph. — This is a simple device which makes use of the magnetic effect of a current. In Fig. 221 the *key*, *k*, and the *sounder* are in circuit with a battery. As with the telephone, the circuit is completed through the earth.

The sender of a message uses the key, while the sounder is in the office of the receiver. When the circuit is closed by pressure on *k*, the *magnet*, *m*, attracts the *armature*, *a*; as soon as *k* is released, *m* is demagnetized and *a* is pulled up by a spring. On the downstroke and the upstroke, *a* hits a point on the frame *f*, making a clicking sound.

Each letter or figure is made by a different combination of dots and dashes, thus (k, ——— – ———; e, –; y, – – – –). A dot is made by a quick touch of the key, a dash by a prolonged pressure upon it. The

operator can tell by the sound whether a dash or dot is made, and the words are easily intelligible to him.

341. Electroplating. — When any body is covered with a thin layer of some metal (gold, silver, nickel, etc.), it is said to be plated. This is usually done by means of electric currents. The process is called *electroplating;* it depends upon the electrolytic effect of a current.

We can perhaps recall our study of *electrolysis.* A circuit was broken, and the ends of the wires attached

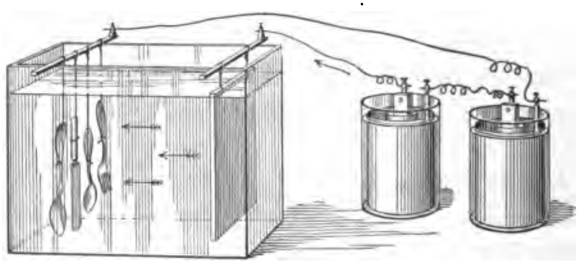

Fig. 222

to metal pieces called *electrodes.* These electrodes were placed in a liquid, and the current passing from one to the other through the liquid decomposed the liquid or broke it up into the substances of which it was made. Some of these went to one electrode, some to the other.

Fig. 222 may help to show how this is used in plating. The articles to be plated are made the *negative electrode,* and a plate of the metal we want to cover them with is made the *positive electrode.* Both are hung in water, in which is dissolved some *salt* of the metal.

As the current passes through the liquid from the positive to the negative electrode, this liquid is decomposed. The *metal* which was in the salt solution goes to the negative electrode, covering whatever is there with a layer of metal, which will stick on because it fits so closely. In this way the article is plated. At present, dynamo currents are largely used for plating.

342. Storage Batteries. — If two electrodes of the same metal be placed in an electrolyte and a current sent through them, the liquid may be decomposed by *electrolysis.* We have learned that in such a case one part of the compound goes to one electrode and another part to the other. The chemical action of these different parts of the compound upon the electrodes will be very different in its nature, and a resulting difference in electrical condition will be established in them. If, now, the generator be removed and the electrodes connected by a conductor, a current will flow through it from one electrode to the other. *The different chemical action upon the two electrodes gives rise to a difference in potential,* and this is great enough to cause a flow through the conductor.

On this principle *storage batteries* are made. Lead is commonly used, and each electrode is composed of many plates. Dynamo currents may be used in *charging* them, and the batteries so charged may be carried to a distance and used to generate considerable currents.

343. Electric Lights. — Electric lights make use of the *thermal* effect of currents. There are two kinds in common use — arc lights and incandescent lights. Both

depend upon this principle, — that *a current flowing through a poor conductor against great resistance heats the conductor till it is luminous.*

344. The Arc Lamp. — This is the big one commonly used for lighting streets in cities. It is simple in its

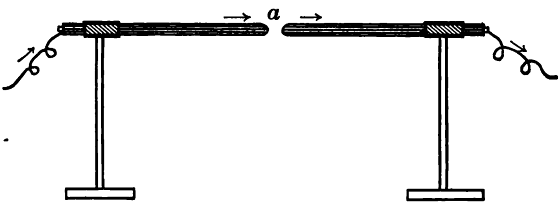

FIG. 223

manner of working. A circuit is broken and two *carbon pencils* (pointed sticks of carbon) are attached, one to each wire. The carbon pencils are placed in loose contact. Now a current is passed through the circuit. Meeting high resistance at this loose contact, it heats the carbon tips to luminosity. The space between them is soon filled with glowing particles, and it becomes a poor conductor; so that when the points are now separated slightly (*a*, Fig. 223) the current continues to flow on through this *arc*. The resistance is still great, however, so that the high degrees of heat and luminosity of the arc and carbon tips are maintained. Thus we have three sources of light waves: the two highly heated tips (Fig. 224) and the luminous mass of particles between them. These pencil points wear out quickly, but the arc

FIG. 224

lamp contains a device for keeping them just the right distance apart. The current used is generated by a dynamo, and must have great electro-motive force.

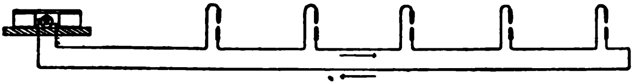

FIG. 225

The lamps on a circuit are arranged *in series*, receiving the heavy main current (Fig. 225).

345. The Incandescent Lamp.— This is the one commonly used in lighting houses, etc. It consists of a glass bulb (Fig. 226), inside of which is a loop of *fine wire*, usually of carbon or platinum. This wire, being small and of a poor conductor, offers great resistance to a current. Thus, when the current passes through it, the wire becomes very hot and luminous.

FIG. 226

The globe or bulb is almost a perfect vacuum; for if air were let in, the wire being so very hot would burn up. These lights also use dynamo currents.

Incandescent lamps require less potential than arcs. They are commonly arranged in *multiple arc* (Fig. 227), the current being taken from the main by means of a transformer.

346. Kathode Rays. — The *Crookes tube* is shown in Fig. 228. Two wires are sealed into a glass tube, from which the air has been removed till only one millionth

of an atmosphere remains. Inside the tube one wire ends in a square of platinum, *a*, and the other in a convex disk of aluminum, *k*. The tube may be put into

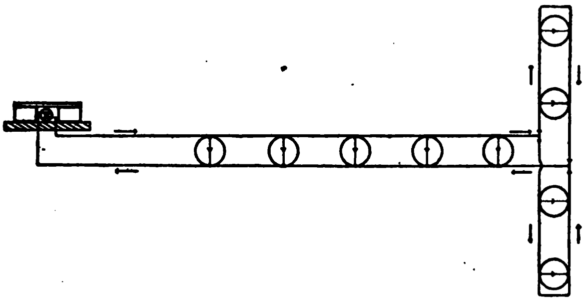

FIG. 227

circuit with the secondary of an induction coil, so that the current shall enter at *a* and go out at *k*; thus *a* is called the *anode* and *k* the *kathode*.

The discharges of the induction coil, passing between *a* and *k* through a high vacuum, give rise to some interesting phenomena. From the kathode tiny particles proceed in straight lines with very great velocity. These particles are exceedingly small, and their velocity is about 20,000 miles per second. That the particles actually move, has been shown by the motion of a light paddle wheel placed in a tube and turned by their impact. For some time these streams of particles from the kathode have been called *kathode rays*.

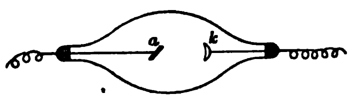

FIG. 228

Plate I shows the appearance of a tube while it is being operated.

347. Röntgen Rays. — Nearly a quarter of a century has passed since Crookes first made known the results of his studies. It was not until early in 1896, however, that the world in general came to know of the wonderful "X-ray," which could stream through so many hitherto opaque bodies.

Röntgen discovered that a certain sort of ray is formed *outside* the Crookes tube, which can not only

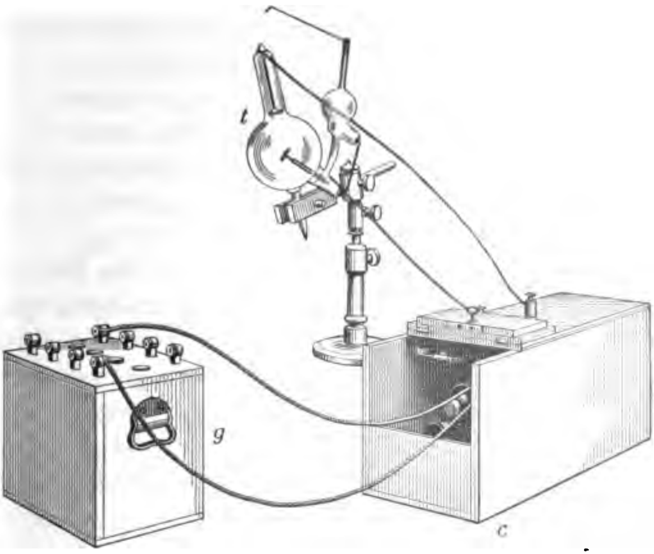

FIG. 229

penetrate many opaque substances but affect the sensitive photographic plate as well. Not knowing much about the cause or nature of the ray, he gave it the name by which it is commonly called, *X-ray.* It is much better to follow the custom of distinguishing

discoveries by the name of their discoverer, and call it the *Röntgen ray.*

Fig. 229 shows the apparatus used in working with the ray. The generator *g* furnishes a current, which is changed by the induction coil *c* into one of high potential. This induction coil discharges through the rarefied gas in the tube *t*, which tube becomes the apparent source of Röntgen rays. While the tube is in operation radiant particles stream from the kathode, as explained in § 346. The impact of these kathode rays upon the glass tube gives rise to Röntgen rays. The latter are a very different kind of radiation from the kathode rays, being probably *ether vibrations* rather than moving particles.

FIG. 230

348. Use of the Ray. — The value of the Röntgen ray lies in the facts that (1) it affects the photographic plate as do light waves, and (2) it passes through different substances *unequally.* For example, the softer parts of the human body are fairly transparent, bones are less so, while metals hardly allow any passage to the rays. With this in mind, we easily see the use of the rays in surgery. Broken bones may be examined accurately; infants may be searched for missing buttons, coins, or pocketknives; and bullets may be located, even though imbedded in bone.

It may be noted that pictures taken by means of the Röntgen ray are life-size *shadow pictures.* A picture of the hand, for example, is taken by laying the hand on a sensitive plate (in a dark room of course) and placing the tube in front of the hand. The picture shows the bones a deeper shade than the soft parts (Fig. 230).

349. Wireless Telegraphy; Hertzian Waves. — Many years ago Maxwell made extensive researches in a field of Physics which now receives much attention,—radiant energy. The term *radiant energy* is used to denote such phenomena as have been seen in connection with heat and light, — energy at one place arousing vibrations in the ether, which transmit this energy with great velocity in straight lines and affect distant bodies of matter.

Among other things, Maxwell suggested that *discharges* across an arc, in circuit with the secondary of an induction coil (see "spark coil," § 327), give rise to *ether disturbances* which extend indefinitely in all directions. The difficulty he found was that these disturbances grow weaker as they proceed, and he could not devise a way to detect them at any distance from their source. It remained for Hertz, in 1888, to prove the theories of Maxwell. He showed that the discharges through the air (the sparks) are each composed of many thousand to-and-fro vibrations per second, and that these vibrations give rise to ether waves, which radiate in all directions and may be detected at some distance. The vibrations are now called *oscillations;* the disturbances in the ether caused by oscillations are frequently called *Hertzian waves.*

350. The Wireless Transmitter. — *Wireless telegraphy* makes use of these Hertzian waves, which need no conductor other than the ether. The *transmitter* (Fig. 231) used in sending a message consists of a generator, *a*, and an induction coil, *c*. By means of a key, *k*, the primary circuit may be closed; a high-potential current will be induced in the secondary, and this is made to discharge across an arc at *b*. The secondary circuit is run up into the air, and the ether about this wire is the source of the Hertzian waves. From this source the waves radiate while the discharges are taking place.

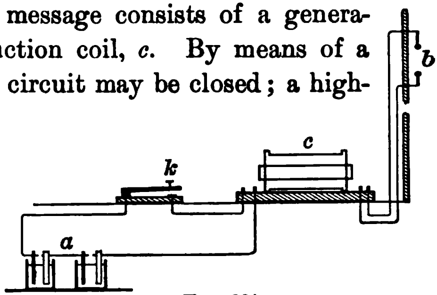

FIG. 231

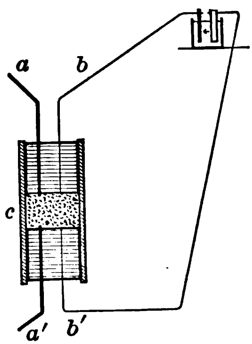

FIG. 232

351. The Receiving Instrument. — The intensity of these waves decreases with the distance, so the difficulty has been that of finding something delicate enough to be affected by them at a distance from the transmitter. Among the devices to meet this need, the most widely used is perhaps the coherer.

The *coherer* (Fig. 232) is a small glass tube, in which are two silver plugs; a space of about one eighth of an inch between these plugs, *c*, is filled with metal filings — commonly silver and nickel. Two wires, *a* and *a′*,

enter the filings, while two other wires, *b* and *b'*, ending in the silver plugs, are in circuit with a battery. The loose filings are a *non-conductor*, so the circuit *bb'* is broken at *c*. Now the value of the coherer lies in this simple fact, that if a Hertzian wave (even a very weak one) passes from *a* to *a'* through the filings, it causes them to *cohere;* while they thus stick together the filings become a good *conductor*, and *this completes the battery*

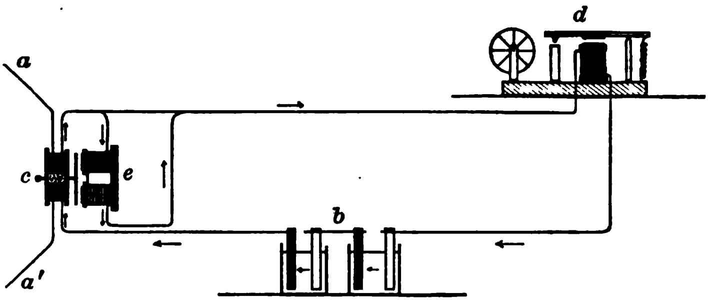

FIG. 233

circuit, *bb'*. At any time, this circuit may be broken by a tap on the glass, which causes the filings to *decohere*.

Fig. 233 shows how the coherer is used by Marconi and others in the receiving telegraph instrument. The waves are received by two thin strips of metal, called *wings*. These are usually on a tall pole, and are connected with the instrument by wires *a* and *a'*. Also *b* is a battery, in circuit with a telegraph inker or a bell at *d*; the circuit is broken by the filings in a coherer at *c*; the wires *a* and *a'* lead to *c*.

When the transmitter sends out waves, they travel with the velocity of light waves, and are received by

the wings of the receiving instrument. From the wings they are conducted by the wires a and a' through the filings in the coherer c; these at once cohere, and serving as a conductor they *close the battery circuit.* The battery current then operates the inker or bell at d. When the circuit is closed, an electro-magnet e moves a striker so as to tap the glass tube and make the filings decohere.

Each instrument may be "tuned" to receive the waves from another, by making the wings of a size to correspond to the length of wave sent out by the other.

QUESTIONS

1. Explain the action of a motor. Is a commutator needed? What sort of current is used?

2. How are electric cars controlled? How are they moved?

3. Explain the action of the electric bell.

4. What is conducted through a telephone wire, sound waves or electric currents? Could messages be sent short distances without any battery current?

5. How is a telegraph message sent? How is the circuit completed?

6. Explain electroplating. Upon which electrode would the article be placed? What would be placed on the other electrode? Why?

7. Explain the storage battery. What does it store up?

8. How is light caused in an arc lamp? an incandescent lamp?

9. How are arc lamps arranged on the circuit? incandescent lamps? Which usually requires a transformer?

10. What is a Crookes tube? Explain the action of currents in forming the kathode ray.

11. What is the Röntgen ray? Where formed?

12. What sort of apparatus furnishes the current for the Röntgen-ray machine?

13. What are Hertzian waves? How great is their velocity?

14. How are wireless telegraph messages sent? Explain.

15. How are they received? What are the "wings"?

16. Explain the action of the coherer.

17. How is the sounder or inker made to work?

18. How are the particles of filings made to decohere?

CHAPTER VIII

A SHORT STUDY OF CHEMISTRY

NOTE. — This chapter is appended for the use of those who desire a brief study of matter from the standpoint of Chemistry. It is not a part of the course in Physics outlined in the previous chapters, and may be used or omitted as the teacher sees fit.

SECTION I

CHEMICAL ACTION

352. Scope of Chemistry. — Chemistry treats of such changes in matter as affect the *nature* of substances. Changes in the shape, size, or state of a body would not affect its nature, and they would be called physical changes. When one substance unites with another, however, so that the resulting body is entirely different, the substance suffers a chemical change.

In Physics the smallest particle of matter is the molecule; this was defined as "the smallest particle which can exist." The chemist tells us, however, that molecules are composed of particles which he calls *atoms*. This need not destroy our idea of molecules; for when a molecule is broken up into atoms, the nature of the substance is changed, so that it no longer exists as such.

353. Elements. — *Elements* have been defined (§ 126) as those simple substances which are not made up of

others. When two or more elements unite to form a new substance, the substance formed is called a *compound.* Clearly, the molecules of a compound will be made of atoms of elements. There can be no such thing as the atom of a compound. The atoms of an element are no different from its molecules in nature; in some elements the molecule is regarded as composed of one atom, and in some cases of more than one.

Chemists usually distinguish about seventy elements; only one quarter of these are at all common. Of gases, *oxygen*, *hydrogen*, *nitrogen*, and *chlorine* are familiar; of liquids, only *mercury;* of solids, *carbon*, *sulphur*, *phosphorus*, and several metals. The great number of compound bodies of matter are all made from the elements.

354. Two Kinds of Chemical Action. — All action which affects the nature of substances may be roughly classed as composition or decomposition. *Composition* includes such changes as build up a new substance from two or more elements. *Decomposition* includes such changes as break up a substance into its parts.

355. Chemical Combination. — When two or more elements unite to form a new substance the process is called *chemical combination.*

Care must be used to distinguish between a *chemical compound* and a *mixture.* Salt and sugar, for example, may be mixed together; they may be ground in a mortar till the tiny grains would appear quite alike; nevertheless the mass is only a mixture, for the particles of salt and sugar are still separate and no new substance has been formed. When chemical combination has taken

place, the nature of the compound is quite different from that of either substance before they united. A mixture contains the unchanged molecules of each of the substances mixed; a compound contains only one kind of molecule, and that is different from those of either element in the compound.

356. Cause of Chemical Action. — Various substances may be *mixed* together and in almost any proportion we may wish. This is by no means true of chemical combination. Every element will *combine* with certain substances, and no others. Also when two elements combine, they do so in *definite proportions;* that is, a certain amount of one element will combine with a certain amount of the other.

Just why certain elements should unite with some others is hard to discover. It seems to be a property of atoms, whereby each sort of atom seeks naturally to unite with those of some other sort, at the same time refusing to unite with still others. This apparent property of atoms is called *chemical affinity*.

The strength or degree of affinity of one atom for others varies with the different sorts. Hence, if a certain atom, *a*, be in a compound with another, *b*, and this compound be brought into contact with a different substance, *c*, whose atoms have a stronger affinity for *a* than *a* has for *b*, the atom *a* will leave *b* and unite with those of *c*. This is the reason why many chemical actions occur when substances are brought in contact.

357. Heat aids Chemical Action. — From the study of combustion (§ 129) we learned that various substances

would unite with oxygen (burn) if sufficiently heated. Common experience shows us many similar examples: gunpowder is a mixture which is ready to unite chemically, but the spark is needed; sulphur and iron filings may remain in contact a long time, but a little heat soon causes them to unite and form a compound. These and many other examples which easily come to mind serve to show the importance of heat as an aid to chemical action.

358. Water as an Aid to Chemical Action.—Very many chemical compounds occur in a solid or crystalline state. As a general rule solids do not often act upon each other by simple contact. Many of these, however, will act readily enough if they are first dissolved in water. The reason is that the molecules of two solids cannot get near enough together to act upon each other, but when changed to liquid form the molecules mix intimately and chemical action occurs.

QUESTIONS

1. Of what does Chemistry treat? What sort of changes would be called chemical changes? Give examples.
2. What is an atom? Do compounds have atoms?
3. What is an element? About how many are there? Name some common elements. What is the difference in structure between the molecule of an element and of a compound?
4. Name the two general sorts of chemical action; show the difference between them.
5. Does chemical action take place between molecules or atoms?
6. What is meant by chemical combination? What is a compound? How is it different from a mixture?

7. Explain what is meant by chemical affinity. Is it the same in degree between all sorts of atoms? How does this explain chemical action by contact?

8. Name examples of chemical action aided by heat. Does heat ever aid decomposition?

9. Show how water may aid chemical action.

SECTION II

SOME CLASSES OF SUBSTANCES

359. Solutions. — When some solid is dissolved in a liquid it is said to be in solution. A *solution* is a liquid which contains a dissolved solid. When the liquid contains all that it can dissolve of the substance, the solution is said to be *saturated.* If more of the solid be added to a saturated solution, it will be *precipitated* to the bottom of the vessel as a solid. The same would happen if some of the liquid were evaporated.

The liquid in which a solid is dissolved is called a *solvent.* Water is the most common solvent. For many uses alcoholic solutions are made; these are called *tinctures.*

360. Acids. — The distinction between various classes of substances is not definitely drawn. In many cases it depends more upon the action of a substance than upon its properties. The name *acid* is applied to a large number of substances which have some common properties. In general, an acid contains hydrogen, which it easily gives up, taking on other substances; it usually has a sharp or sour taste.

Acids are common and important; *sulphuric acid* is much used in mechanic arts; *nitric acid* and *hydrochloric acid* are equally familiar. Lemons and oranges owe much of their flavor to the acids they contain, and a great many fruits contain lesser amounts. Of course the acids vary much in strength; some of the stronger ones (*e.g.* nitric and sulphuric) act upon the skin and clothing quickly.

361. Acid-Forming Substances. — Many of the elements are distinguished for their readiness to unite with others in forming acids. Among these are *sulphur*, *nitrogen*, and *chlorine*, which occur in the three acids named above (§ 360); *phosphorus* is found in phosphoric acid, and *carbon* occurs in a great number of such acids as are found in fruits.

362. Bases and Alkalis. — Quite the opposite of acids in their action is a group of compounds called *bases*. These are not so common as the acids, and only a few of the stronger bases are familiar; the strong bases are called *alkalis*. Of these, three are common, — *ammonium hydrate* (ammonia water), *caustic soda*, and *caustic potash*.

363. Base-Forming Substances; Metals. — The division of the elements according to whether they form bases or acids is by no means definite. We may say, however, that most of the elements occur in one and only one of these two classes. The number which unite with others to form bases is large, and it includes some important elements.

The *metals* are elementary substances and are classified as base-forming elements. In general, a metal is

described as a substance which may replace the hydrogen in an acid. Of course this does not mean that the metal then becomes a part of the acid, for when the change has taken place the compound is no longer an acid (see § 364).

Metals usually occur in the earth. They are sometimes found pure, but more often in combination with other elements; a mass of rock containing metal is called *ore.* Of the metals, *iron*, *copper*, *zinc*, *gold*, *silver*, *tin*, *lead*, *mercury*, *potassium*, *sodium*, *calcium*, and *platinum* are familiar. Many substances (*e.g. brass*, *german silver*) which may at first seem to be metals, are simply mixtures of two or more metals; they are called *alloys.*

364. Salts.—We have learned that an *acid* may give up its hydrogen and take on some other substance in place of it; also that the *metals* may replace the hydrogen in an acid. The compound formed when a metal replaces the hydrogen in an acid, is called a *salt* or a metallic salt. An example may make this clear: hydrochloric acid is made of hydrogen and chlorine. If a piece of the metal sodium be placed in this acid, the compound will break up; hydrogen will be set free and the sodium will unite with the remaining chlorine atoms, forming *sodium chloride*, a salt. This is because the chlorine atoms have a stronger affinity for the sodium than for the hydrogen atoms.

Of the *metallic salts*, sodium chloride (common salt) is most familiar. The number of different kinds is very large and they form a most important group of compounds. Among the common ones may be mentioned

copper sulphate, *ammonium chloride* (sal ammoniac), *potassium chlorate*, *sodium carbonate*, *iron sulphate*, *zinc sulphate*, *mercuric chloride* (corrosive sublimate), and many others.

The alkalis also have a similar power to unite with certain acids. In such cases the compound formed is sometimes called an *alkali salt.*

365. Carbon Compounds. — *Carbon* unites with *hydrogen* and *oxygen* in so many different proportions that the resulting compounds form a separate branch of study in Chemistry. These substances are classed in groups, among which are a few which interest us: the *hydrocarbons* (composed of carbon and hydrogen) include kerosene, benzine, naphtha, and paraffin; the *acids*, such as occur in fruits, woods, oils, etc.; the *carbohydrates*, starch, sugar, etc.; and the *alcohols.* Among the latter are ethyl alcohol (common alcohol), wood alcohol, and glycerine.

366. Fats and Oils. — An alcohol may unite with certain acids, in which case an *ethereal salt* would be formed.

Fats are ethereal salts, in which the alcohol *glycerine* is united with three acids (usually *palmitic*, *stearic*, and *oleic* acids). Fats and oils occur in animal or vegetable matter. They are formed as a result of natural processes which take place in different sorts of living matter, — processes which man is frequently unable to imitate by artificial means. The acids which occur in fats are called *fatty acids.*

QUESTIONS

1. What is a solution? a saturated solution? Under what conditions may the solid be precipitated from a solution?
2. What is a solvent? a tincture? Name some common solvents.
3. How may an acid be defined? Name some familiar acids.
4. Name some acid-forming elements. What acid does each form?
5. How would you describe a base? an alkali? How does their action compare with that of an acid? Name some alkalis.
6. Describe a metal. Name some metals. Are the metals elements?
7. What is an alloy? Is it an element? Is it a compound?
8. How would you describe a salt? What is a metallic salt? an alkali salt? an ethereal salt? Name some common salts.
9. Of what elements are most of the carbon compounds made? Name some groups of carbon compounds. Name some substances from each group.
10. What is a fat? Of what substances are fats composed? What is a fatty acid?

SECTION III

SOME COMMON SUBSTANCES

367. Water.—Water is a chemical *compound* in which the elements are *hydrogen* (two parts) and *oxygen* (one part). Hydrogen is a gas which burns readily; oxygen is a gas which supports combustion. When hydrogen is burned in the presence of oxygen, the process is an act of chemical union (§ 129); two hydrogen atoms unite with every atom of oxygen, and the new substance formed is water.

The source of water supply on earth is the ocean. Streams, rivers, and lakes get their water from the

rainfall or from springs; the springs contain water which once fell on the surface of the earth as rain, and the latter in turn simply returns to earth the water which was once evaporated from its surface. Rain water is usually nearly pure, especially that which falls after the first part of a shower has washed other particles out of the air.

Mineral waters contain small amounts of mineral matter in solution. This is because the water flows underground and dissolves certain substances out of the rocks through which it passes. Such waters are said to be "hard"; they are sometimes beneficial to drink, but are almost useless for cleansing purposes. *Hard water* may sometimes be made "soft" by boiling, sometimes by the addition of a small amount of lime.

368. The Soil. — The earth seems to be made of rock, which is nearly everywhere covered with a layer of *soil.* The soil varies in depth, but the average is only a few feet. It consists largely of *decomposed rock*, mixed with a small amount of decayed vegetable or animal matter.

The causes which have broken up rock material into soil are several: we may mention the action of heat, frost, air, rain, flowing water, winds, ice, the ocean, the growth of vegetation, etc.

369. Air. — Air is a *mixture* of gases, not a compound; for this reason we cannot say exactly of what substances it is composed, or how much of each it contains. Nevertheless, pure air is commonly considered as containing three gases, — *nitrogen* (about four fifths), *oxygen* (one fifth), and *carbon dioxide* (a small fraction of one per

cent). Besides these, other gases are sometimes present, as well as dust particles, moisture, and bacteria.

The active element in air is oxygen; it supports animal life and aids in combustion. Without oxygen in the air no fires would burn, and animals would die by suffocation. Carbon dioxide serves in a similar way to support plant life. The nitrogen is not active but still it serves an important use, for without its presence the action of the oxygen would be far too strong.

370. Carbon Dioxide. — Carbon dioxide or "carbonic acid gas" is a *compound* of the solid *carbon* with the gas *oxygen.* The substance itself is a gas. It is formed when any of the common fuels (coal, wood, kerosene, gas, etc.) are burned in air, for the fuel supplies carbon and the air oxygen. The little holes in bread or cake are filled with it (before being cut), and it causes the sparkling of soda waters.

The *animals* (including man) inhale air. The oxygen is carried, by the blood, from the lungs to all parts of the body; here it unites with carbon, and this being a process of combustion, supplies heat and energy to the body. The carbon dioxide formed by this union passes out into the air again, making it impure. *Plants* take in air, but use the carbon dioxide, so that the air they send out is partly purified.

371. Starches and Sugars. — These substances are found in seeds, roots, stems, leaves, and fruits of plants. In most of these cases they represent *nourishment*, either for the present use of the plant or stored for future use.

Both starch and sugar are *carbohydrates*, being made of *carbon*, *hydrogen*, and *oxygen* (§ 365). Just how these elements are put together in the proper proportions is still a problem to man; it is a simple matter to discover what the proportions are, but to make the elements unite is the difficulty. The process is daily performed, however, in the leaves of plants. Hydrogen and oxygen are taken in by the roots as water, and carbon is taken in by the leaves from the air; in some way the *chemical effect* of the sun's rays seems to assist the substance of the leaf, and the three elements are formed into *starch*. *Sugar* is formed from starch by further changes.

372. Wood. — Wood is simply a mass of wood fiber, or *cellulose*. This is made of the same elements as starch, and is formed from the starch which is carried in the sap of a plant, by natural action of the plant cells.

373. Coal. — Ages ago, certain parts of the earth were covered with thick vegetation. When any of these plants died and were by some chance covered up (by water, mud, etc.), a sort of *partial decomposition* went on in the mass thus covered. This removed some of the gases from the woody material, but left much of its solid substance, particularly carbon. In time the mass hardened, and the result of this process is now an important fuel, *coal*.

As a fuel, coal is better than wood because it does not burn up so quickly. This is due to the large amount of carbon which it contains.

374. Glass. — Common glass is made by melting sand with soda and lime. Sand is composed of *silicon* and

cent). Besides these, other gases are sometimes present, as well as dust particles, moisture, and bacteria.

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373. Coal. — Ages ago, certain parts of the earth were covered with thick vegetation. When any of these plants died and were by some chance covered up (by water, mud, etc.), a sort of *partial decomposition* went on in the mass thus covered. This removed some of the gases from the woody material, but left much of its solid substance, particularly carbon. In time the mass hardened, and the result of this process is now an important fuel, *coal*.

As a fuel, coal is better than wood because it does not burn up so quickly. This is due to the large amount of carbon which it contains.

374. Glass. — Common glass is made by melting sand with soda and lime. Sand is composed of *silicon* and

cent). Besides these, other gases are sometimes present, as well as dust particles, moisture, and bacteria.

The active element in air is oxygen; it supports animal life and aids in combustion. Without oxygen in the air no fires would burn, and animals would die by suffocation. Carbon dioxide serves in a similar way to support plant life. The nitrogen is not active but still it serves an important use, for without its presence the action of the oxygen would be far too strong.

370. Carbon Dioxide. — Carbon dioxide or "carbonic acid gas" is a *compound* of the solid *carbon* with the gas *oxygen*. The substance itself is a gas. It is formed when any of the common fuels (coal, wood, kerosene, gas, etc.) are burned in air, for the fuel supplies carbon and the air oxygen. The little holes in bread or cake are filled with it (before being cut), and it causes the sparkling of soda waters.

The *animals* (including man) inhale air. The oxygen is carried, by the blood, from the lungs to all parts of the body; here it unites with carbon, and this being a process of combustion, supplies heat and energy to the body. The carbon dioxide formed by this union passes out into the air again, making it impure. *Plants* take in air, but use the carbon dioxide, so that the air they send out is partly purified.

371. Starches and Sugars. — These substances are found in seeds, roots, stems, leaves, and fruits of plants. In most of these cases they represent *nourishment*, either for the present use of the plant or stored for future use.

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374. Glass. — Common glass is made by melting sand with soda and lime. Sand is composed of *silicon* and

oxygen; soda and lime contain the elements *sodium, calcium, oxygen,* and *carbon.* When the mass is heated, the gases, oxygen and carbon dioxide, pass off, leaving the silicon, sodium, and calcium united in the form of glass.

Other substances may be used in place of the soda and lime. *Lead oxide* and *potassium carbonate* are often used in other varieties of glass.

375. Soap. — A soap is an alkali salt of a fatty acid. We have learned that the fats are composed of fatty *acids* and *glycerine.* If a *fat* be boiled with some *alkali* (*e.g.* caustic potash), the acids will unite with the alkali, forming *soap,* and the glycerine will be set free.

The action of soap is not so much upon the dirt as upon the oily film which forms over the skin. This oily substance is dissolved by the soap, leaving the water free to act upon the foreign matter and wash it away.

376. Mortar and Plaster. — *Mortar* is made of lime (*calcium oxide*) and sand, mixed with water. When applied to any surface the calcium oxide slowly takes on carbon dioxide from the air, forming *calcium carbonate.* This substance is very hard, and is useful as a cement or a covering for the walls of a room.

Plaster is made by heating a mineral, *gypsum.* This mineral when heated changes to a white powder called *calcium sulphate,* or plaster of Paris. When the powder is mixed with water it soon "sets," forming a smooth, hard substance. Plaster is finer than mortar; it is put to similar uses, but for better grades of work.

QUESTIONS

1. Is water a compound or a mixture? What elements does it contain? in what proportion? Under what conditions do they unite?

2. What is the great source of water supply on earth? From what source does spring water come? rain?

3. What is mineral water? How is it formed? How may hard water be made soft?

4. Of what is the soil composed? How deep is it (average)?

5. Name some causes which have broken up rock into soil.

6. Is the air a mixture or a compound? What substances does pure air usually contain? How much of each? What other substances are sometimes found in air?

7. What is the active element in the air? Name some of its effects. What is the difference between air which is inhaled by an animal and that which is exhaled?

8. Of what elements is carbon dioxide made? Is it a solid, a liquid, or a gas? Where is it sometimes found? How is it used?

9. What sort of substances are starches and sugars? What elements compose them? Where are they found?

10. Where is starch made? How? Of what use is it to a plant?

11. Of what is wood composed?

12. Show how coal has been formed from wood. Why is it a better fuel for some purposes?

13. How is glass made? What elements does it contain?

14. What is a soap? How may it be made? What other substance is set free at the same time?

15. Explain the action of soap.

16. How is mortar made? plaster? How does mortar become hard? To what different uses is each put, and why?

SECTION IV

COMMON CHEMICAL PROCESSES

377. Oxidation. — *Oxygen* is a very active element, combining with a large number of substances by a process called *combustion.* We have studied this (§ 129) and have learned that the process goes on at certain high temperatures. In many cases, however, oxygen unites with other elements at ordinary temperatures, though very slowly.

Several of the *metals*, for example, become covered with a dull coating on being exposed to the air for a time. This dull covering is a compound that is formed by the quiet chemical union of the metal with oxygen from the air. The product formed by the action of oxygen on a metal is called an *oxide;* the process is called *oxidation.*

Rust on a metal is simply a layer of the oxide. Iron rust is formed by the action of oxygen upon iron. The presence of water on the metal may assist the process by bringing the oxygen in closer contact with the atoms of iron (§ 358); but it is oxygen and not water which forms the rust.

378. Decomposition. — The process of *decomposition*, or *decay*, produces results which are rather different from those just described. Like oxidation, however, decay may go on very quietly and slowly. Almost anything of plant or animal origin — dead leaves or trees, fruits of all kinds, and animal bodies — is subject to

decay if left for a long time in the air. On the other hand, the same substances may be kept for a long time if tightly sealed in coverings which admit no air.

Just what causes the decomposition in every case, is hard to determine. Sometimes it is due to the action of *oxygen*, no doubt; in many cases it is thought to be due to *bacteria* in the air (§ 369). Fruits are *preserved* by heating them (to kill the bacteria) and at once covering them in air-tight jars. Many vegetable and animal substances are now preserved in *cold storage*, at temperatures so low as to prevent action of the agent which causes the decay.

When plant or animal matter decomposes, much of its substance passes off in the form of gases.

379. Explosions.—An *explosion* is a sudden and violent chemical action. Such explosives as *gunpowder*, *nitroglycerine*, *dynamite*, etc., are *mixtures* of elements which have strong affinity for each other; but these elements cannot unite chemically unless the proper cause be presented. Under the impulse of this cause (it may be a spark, a jar, or a blow) chemical union at once takes place among the particles which are so ready to unite. This sudden combination forms a large amount of *gas*, which expands so rapidly as to exert great force upon anything which would confine it.

380. Fermentation. — When fruit juices which contain *sugar* are allowed to stand for some time, they undergo a change called *fermentation*. As a result of this change, the liquid is found to contain alcohol, some acid, and less than the original quantity of sugar.

Fermentation of fruit sugar is due to the action of different *ferments*. These get into the liquid and act upon the sugar, converting it into *alcohol* and *carbon dioxide*. Unless the juice is in an air-tight vessel the carbon dioxide escapes, leaving the alcohol, together with some of the sugar and an acid. It is in this manner that wines are made from grape juice.

The juice from apples, when slightly fermented, becomes cider. As the process continues, a substance in the cider (called *mother of vinegar*) acts upon the alcohol which is formed, changing it into *acetic acid*. When the fermented apple juice contains acetic acid, it is called *vinegar*.

381. Bread Making. — *Yeast* is a vegetable ferment, — that is, a substance which may act upon sugars and cause fermentation. Wheat flour contains *starch*; also *gluten*, which mixes with water and forms the sticky substance in dough.

When flour, water, and yeast are mixed and set in a warm place, the yeast acts upon the starch, changing a portion of it to sugar. The sugar is further acted upon by the ferment and is broken up into alcohol and carbon dioxide. Most of the alcohol is evaporated, but the *carbon dioxide* remains in the dough, making it "light." The heat in baking stops the action of the yeast, so that no more gas forms.

Baking powders also serve to form carbon dioxide, though in a different way. Most of them make use chiefly of *sodium bicarbonate*, a substance which gives off carbon dioxide when heated.

382. Disinfection. — The *bacteria*, about which we have studied somewhat, are of many kinds. Some of them are commonly called *disease germs*, because of their power to produce and to spread certain diseases. Methods for destroying these bacteria are carefully studied; the subject is called *disinfection.*

In general, *heat* is a good *disinfectant;* the temperature of boiling water kills the germs in a short time. *Fresh air* and *sunlight* destroy some kinds of bacteria, while for many common purposes nothing seems to be much better than a weak solution (1 part in 1000) of *corrosive sublimate.*

QUESTIONS

1. What is meant by oxidation? What name is given to this process when it is carried on rapidly, at high temperatures?

2. What class of elements are acted upon slowly when exposed to the air? What is the result of such action?

3. How is iron rust formed? What part does the water play in its formation? What is an oxide?

4. Define decomposition. In what sorts of bodies does decay commonly go on? under what conditions?

5. What causes quiet decomposition in bodies exposed to the air? How may decay be prevented?

6. What compound is subject to fermentation? Into what substances is it changed by the process? Explain the fermentation of fruit juices.

7. From what is vinegar made? How? What substance is formed which makes it useful?

8. Explain the action of yeast in the process of bread making. What causes the changes? How does baking powder act to produce similar results?

9. What is an explosion? Are explosives mixtures or compounds? What is formed when an explosive is fired? Why is great force exerted by it?

10. What is the purpose of disinfection? Why is it desirable? Explain some methods of disinfection.

APPENDIX A

NUMERICAL PROBLEMS

[References are to pages in the book, where necessary explanations may be found.]

FLUID PRESSURE. PAGES 36–44

A cubic centimeter of distilled water at 4° C. weighs one gram. In computing the weight of a body of water, find its volume in cubic centimeters and allow one gram for every cubic centimeter.

PROBLEMS

1. A rectangular jar is 12 cm. long, 8 cm. wide, and 10 cm. deep. Find the pressure on its bottom, if it is full of water.

2. In the same jar, compute the pressure upon one end when it is full.

3. Suppose a square piece of paper, 2 cm. on each side, to be pasted inside the jar so that its upper edge is parallel to the upper edge of the jar and 4 cm. below it. What is the pressure upon the paper?

4. A glass tube 1 meter long is run through a rubber stopper exactly to its lower surface; the stopper is fitted tightly into a bottle so that its lower surface is 7 cm. above the bottom of the bottle, and the whole is filled with water. If the area of the bottom is 15 cm.^{2}, what is the pressure upon it? The lower face of the stopper has an area of 4 cm.^{2}; compute the pressure upon it.

5. The pressure upon every square decimeter at the bottom of a reservoir is 90 kilograms. How deep is the water?

6. A dam is $6\frac{1}{2}$ m. long and $8\frac{1}{2}$ m. high. When the water rises to a point 50 cm. below the top, how great is the pressure upon the dam?

7. The large piston of an hydraulic press has an area of 450 $cm.^2$, and the plunger in the pump has an area of 3 $cm.^2$. How much force applied to the plunger will be needed in order to exert a force of one ton on the large piston?

8. Given an hydraulic press, the large piston having a cross-sectional area of 120 square inches and the plunger 1 square inch. How much pressure may be produced if a force of 20 pounds is applied to the plunger?

9. Using the hydraulic press described in Ex. 8, if the plunger makes a stroke of ten inches, how far would the large piston move during each stroke? How many strokes would be needed to make the large piston move upward one foot?

Buoyancy and Specific Gravity. Pages 48–53

PROBLEMS

1. A stone when held in water seems to weigh 27 grams less than in air. What is the volume of the stone?

2. A piece of wood floats with one third of its volume above the surface of water. If its volume is 36 cc., how heavy is it?

3. An iron anchor weighs 36 kilograms. If it is immersed in water how much will it seem to weigh? (sp. gr. of iron 7.2.)

4. A piece of wood floating on water displaces 15 cc. of the liquid. How heavy is the wood? If its sp. gr. is .75, what is its volume?

5. If a solid ball of copper (sp. gr. 8.8) sinking into water displaces 5 cc. of the liquid, how heavy is it?

6. A hollow ball of tin weighs 20 grams. How large must it be in order that it shall not sink in water?

7. A piece of ore weighs 88.4 grams. Immersed in water it weighs 71.4 grams. Find the sp. gr. of the ore.

8. A cube of cork has a volume of 20 cc. Floating on water it displaces 4 grams of the liquid. Find its sp. gr.

9. If a lump of lead weighing 12 ounces be placed in mercury, how much will it displace?

Velocity and Acceleration. Pages 77–78

Velocity is rate of change of position, and so may be expressed as space traversed in a unit of time. Thus, letting $v =$ the uniform or average velocity of a moving body, $s =$ the total distance traversed, and t the number of units of time during which it moves, we find that

$$v = \frac{s}{t}. \tag{1}$$

From this may be derived

$$s = vt, \quad \text{or} \quad t = \frac{s}{v}.$$

PROBLEMS

1. A train moves between stations 36 miles apart in 45 minutes. Find its average velocity expressed in miles per minute and then in miles per hour.

2. If a bullet moves with an average speed of 1250 feet per second, how far will it go in 3 seconds?

3. Running at an average rate of 12 feet per second, how long will it take a boy to run one half mile?

4. Suppose the earth's circumference to be 25,000 miles and that it rotates on its axis once in exactly 24 hours. What would be the average velocity (in miles per minute) of a point on the equator?

5. When an express train travels at an average rate of 80 feet per second, how long will be needed for it to run 10 miles?

Acceleration is rate of change of velocity. In order to find the acceleration of any motion, then, we must know at least two of its velocities, — one at the beginning of the change and the other at its completion. The first is called initial velocity, and is expressed as v_0; the other is called final velocity, and is written v_1. The difference between

these two velocities, that is, $v_1 - v_0$, is the increase in velocity during the whole time. If the increase has been constant, the acceleration a may be found by dividing this difference $(v_1 - v_0)$ by t, the number of units of time elapsed. Thus we have

$$a = \frac{v_1 - v_0}{t}. \qquad (2)$$

This may also give

$$v_1 - v_0 = at, \quad \text{and} \quad t = \frac{v_1 - v_0}{a}.$$

If the speed is being retarded, v_0 is greater than v_1, and the acceleration is negative.

PROBLEMS

6. A moving body has a velocity of 10 feet per second; 3 seconds later it has a velocity of 22 feet per second. What is its acceleration?

7. Starting from a state of rest, in ten seconds a bicycle rider attains a velocity of 15 feet per second; what is his acceleration?

8. A train moving at a rate of 60 feet per second is brought to a stop in half a minute. What is its (negative) acceleration?

9. Suppose a train can start from a state of rest with a constant acceleration of 2 feet per second. In how many seconds will it have a velocity of a mile a minute (88 ft. per second)?

10. The velocity of a sled changes from 20 feet per second to 14 feet per second in 12 seconds. If its acceleration remains constant, how long before it will stop?

The *distance s* traversed by a body whose motion is being uniformly accelerated, may be found as follows.

If v_0 = its initial velocity and v_1 = its final velocity, the average velocity during the period of acceleration is of

course $\frac{v_0 + v_1}{2}$. Since it moves with this average speed during t units of time, the distance s traversed is

$$s = \left(\frac{v_0 + v_1}{2}\right) \times t. \tag{3}$$

When the body starts from a state of rest, $v_0 = 0$ and (3) becomes $s = \left(\frac{0 + v_1}{2}\right) \times t = \frac{v_1}{2} \times t$. But in such a case the velocity v_1 is of course equal to the acceleration a multiplied by the number of units of time t; that is, $v_1 = a \times t = at$. Substituting this in the formula for s last given, we have $s = \frac{at}{2} \times t$; this may be written

$$s = \frac{at^2}{2}. \tag{4}$$

PROBLEMS

11. A rolling stone passes a point on a hillside, moving at the rate of 4 meters per second. Fifteen seconds later it has a velocity of 8 meters per second. How far has it gone in the meantime?

12. A train starting from a station acquires a velocity of 50 feet per second in 30 seconds. How far away is it?

13. If a trolley car starts from a state of rest and moves with a constant acceleration of 3 feet per second, how far does it move in 16 seconds?

14. A cyclist traveling at a rate of 800 feet per minute arrives at the top of a hill. In 30 seconds he is at the foot of the hill, moving with a speed of 2000 feet per minute. How long is the hill?

Action of Two Forces. Pages 82–83

To find the effect of two forces acting upon a body in different directions at the same time, suppose a force of 15 pounds and another of 10 pounds to act together upon

a body at *a* in two directions that make an angle of 60° with each other. From any point *a* draw *ab* to a scale, making it 15 units long; then draw *ac* at an angle of 60° with *ab*, making *ac* 10 units long. Now the lines *ab* and *ac* represent the direction and intensity of the two forces. Complete a parallelogram, of which *ab* and *ac* are adjacent sides; draw the diagonal *ad*. This diagonal shows the direction that the body will take; measure it by the same scale used for the sides, and the number of units of its length represents the intensity of the force with which the body moves. The forces represented by *ab* and *ac* are called *components;* that shown by *ad* is the *resultant.* This method may be applied in solving problems.

PROBLEMS

1. Two forces act upon a body at right angles, one with an intensity of 20 grams and the other with an intensity of 12 grams. Show the direction and intensity of the resultant.

2. Two boys together pull upon a cart; one pulls directly east with a force of 11 pounds and the other pulls southeast with a force of 8 pounds. Show the direction that the cart takes and the intensity of the resultant.

3. The resultant of two forces has an intensity of 16 grams and makes an angle of 30 degrees with one of the components. If that component force is 10 grams, what is the other?

4. Two boys pull on a rope in opposite directions with forces of 32 and 27 pounds respectively. What is the direction of the resulting motion and what is its intensity of force?

5. A body is acted upon by forces of 7 and 12 pounds. What is the greatest and what is the least resultant of these forces acting at the same time?

Momentum. Page 86

PROBLEMS

1. If a cannon ball has a mass of 150 pounds and a velocity of 2000 feet per second, how does its momentum compare with that of a freight car whose mass is 22,000 pounds and velocity 10 feet per second?

2. Compare the momentum of two bodies, a having a mass of 20 grams and a velocity of 325 cm. per second, and b a mass of 3 grams and a velocity of 15 meters per second.

3. A baseball is thrown with a velocity of 10 feet per second and again with a velocity of 15 ft. per second. While moving with that velocity, how much more force would be needed to stop it in the second case?

Pendulum. Page 102

Three of the laws of the pendulum will be considered here. These may be stated as follows:

(1) The time of each vibration of a pendulum varies directly as the square root of its length. Let $t =$ the time of a vibration and $l =$ the length of one pendulum, and t' and l' the time and length of another; then

$$t : t' = \sqrt{l} : \sqrt{l'}. \qquad (1)$$

(2) The number of vibrations in a certain period of time varies inversely as the square root of the length of the pendulum. If n and n' represent the number of vibrations of two pendulums in the same period of time, we have

$$n : n' = \sqrt{l'} : \sqrt{l}. \qquad (2)$$

(3) The time of one vibration of a given pendulum varies inversely as the square root of the force of gravity.

From these laws we may obtain a formula for finding the value of g (*i.e.* the acceleration of gravity) at different

points on the earth. By a mathematical process we find $t = \pi\sqrt{\frac{l}{g}}$, from which may be obtained

$$g = l\left(\frac{3.1416}{t}\right)^2, \tag{3}$$

in which g is the acceleration of gravity, l the length of a pendulum, and t the time (in seconds) of one vibration. The value of π is approximately 3.1416.

PROBLEMS

1. Compare the time of vibration of a pendulum 36 cm. long with that of another whose length is 16 cm.

2. If a pendulum vibrates once in one second, what is the time of vibration of another pendulum four times as long?

3. The time of vibration of one pendulum is one fourth that of another. The first is 25 cm. long; how long is the other?

4. A pendulum makes one vibration per second. If another pendulum is one ninth as long, what is its time of vibration?

5. Two pendulums are respectively 225 cm. and 400 cm. in length; compare the number of vibrations they would make in a certain period of time.

6. One pendulum is 64 cm. long, and another has a length of 25 cm. While the first is making 20 vibrations, how many will the second make?

7. If at a certain point the time of vibration of a pendulum 1 meter long is 1.012 seconds, what is the acceleration of gravity at that point?

8. The seconds pendulum at Boston is 0.9935 m. in length. What is the acceleration of gravity at Boston?

9. If a pendulum clock keeps correct time at a point on sea level at the equator, will it gain or lose when carried away from the equator, its altitude remaining the same?

10. Suppose a pendulum one meter long vibrates once every second. What is the acceleration of gravity at that point?

11. If a pendulum one meter long makes one vibration per second, how long is a pendulum that makes three vibrations per second?

12. Compare the lengths of two pendulums, one of which makes 36, and the other 90, vibrations per minute.

FALLING BODIES. PAGES 103–104

Since a freely falling body is acted upon constantly by gravity with no opposition (except slight resistance offered by the atmosphere), we may expect the laws of falling bodies to involve the formulæ for uniformly accelerated motion. Thus, if a body falls freely from a state of rest, its velocity is constantly increased by the action of gravity. At the end of any second of its fall the *velocity* may be found by using the formula

$$v = at, \tag{1}$$

where t is the number of the second and a is the acceleration due to gravity. To find the *distance* traversed during any number of seconds of falling we use the formula for distance,

$$s = \frac{at^2}{2}, \tag{2}$$

where $s =$ the entire distance, a the acceleration, and t the number of seconds that the body has been falling freely.

The acceleration due to gravity is found by experiment to be a little more than 32 feet per second. In these problems it may be considered as 32 feet per second, or as 980 cm. per second.

PROBLEMS

1. How far will a body fall in 3 seconds?

2. What is the velocity of a freely falling body at the end of four seconds?

3. If a body has a velocity of 176 feet per second, how long has it been falling?

4. Find the distance that a body will fall in one second. Express the result in feet and in centimeters.

5. A freely falling body has a velocity of 160 feet per second. How far has it fallen?

6. Compare the velocity of a freely falling body at the end of 3 seconds with that of a train moving at the rate of a mile a minute.

7. If a body has fallen 256 feet, what is its velocity at the end of this distance?

8. How far would a body fall in 10 seconds?

9. If it could fall freely and with uniform acceleration for so long a time, what would be the velocity of a falling mass at the end of a minute?

Force

From the second law of motion (§ 66) we learn that a change of momentum is proportional to the amount of force and the time that it acts. This may be expressed in the formula

$$ft = mv,$$

where f = the force used, t = time, and mv (mass $\times$ velocity) = momentum (§ 71). From this equation we may obtain

$$f = \frac{mv}{t}, \qquad (1)$$

or, since $\frac{v}{t} = a$ (acceleration),

$$f = ma. \qquad (2)$$

A unit *force*, then, is the amount of force necessary to give to a unit mass a unit velocity in a unit of time. If the unit mass is one gram, the unit velocity one centimeter per second, and the unit time one second, the unit force is one *dyne*. That is, a dyne is the amount of force that will give to a gram of matter a velocity of one centimeter per second in one second of time. The dyne is commonly used as a unit of force and is independent of gravity; therefore

it is called an absolute unit. This system, based upon the centimeter, gram, and second, is called from those units the C.G.S. system.

PROBLEMS

1. How many dynes of force will be needed to give to a 5-gram mass an acceleration of 30 cm. per second?

2. If a constant force of 16 dynes acts upon a mass of 4 grams, what is the acceleration?

3. What force applied to a mass of 50 grams will increase its velocity at the rate of $2\frac{1}{2}$ cm. per second?

4. If a force of 600 dynes imparts to a pebble a velocity of 40 cm. per second in 2 seconds, what is the mass of the pebble?

By formula (1): $600 = \frac{m \times 40}{2}$. $1200 = 40\,m$. $m = 30$ grams.

5. A force of 350 dynes acts upon a mass of 25 grams for 4 seconds. What velocity is given to the mass?

6. How long must a force of 20 dynes act upon a mass of 4 grams to give it a velocity of 15 cm. per second?

7. What force applied to a mass of 5 grams will give to it a velocity of one meter per second in 15 seconds?

8. What velocity will a force of 8 dynes impart to a 2-gram mass in 5 seconds?

9. How many dynes will be required to give a mass of 1 kilogram an acceleration of 1 cm. per second?

10. A force of 60 dynes acting for 8 seconds will give a velocity of 120 cm. per second to what mass?

11. If the acceleration due to gravity is 980 cm. per second, how many dynes of force does the earth exert in making a five-cent piece (say 5 grams) fall for one second?

12. If a force of 175 dynes acts upon a 10-gram mass for 5 seconds, what velocity will be given to the mass?

13. Find the acceleration when a force of 18 dynes acts constantly upon a 3-gram mass.

14. How great a force is required to impart to a mass of 100 grams an acceleration of 5 cm. per second?

Work and Energy. Page 105

Work is measured in terms of the force acting (f) and the space (s) through which it acts. Thus we have the simple formula for work,

$$w = fs. \tag{1}$$

Since energy is considered as the ability to do work, we may express the energy of a moving body (*kinetic energy*) by the work that it would do upon any body that stopped it. The formula for kinetic energy may be derived as follows. Since the energy of motion of a body may be expressed by the work it can do, putting e (kinetic energy) in place of w (work) in (1), we have

$$e = fs.$$

Now $f = ma$ (p. 366), so that $e = fs$ becomes

$$e = mas. \tag{2}$$

Also we have found (p. 361) $s = \frac{at^2}{2}$; but since $at = v$ (p. 365), the formula $s = \frac{at^2}{2}$ may be written $s = \frac{v^2}{2a}$. Substituting this value for s in the formula (2), we have

$$e = \frac{mv^2}{2}. \tag{3}$$

Different units of work are named; foot pounds, kilogram meters, and dyne centimeters, for example. In the latter, a force of one dyne acting through one centimeter of space is called a dyne centimeter or *erg*. Units of energy are sometimes expressed in the same terms. The formula (3) may be used to find the kinetic energy of a body in ergs, if its mass is stated in grams and its velocity in centimeters per second.

If the kinetic energy is to be expressed in foot pounds or kilogram meters, the formula becomes

$$e = \frac{mv^2}{2g}, \tag{4}$$

where g is the acceleration due to gravity. When the mass is stated in pounds and the velocity in feet per second, the value of g is 32 (*i.e.* 32 feet per second); when the mass is stated in kilograms and the velocity in meters per second, g has a value of 9.8 (p. 365).

PROBLEMS

1. How much work is done when a force of 1 dyne acts upon a mass through a space of 5 cm.?

2. How many foot pounds of work are done upon a mass of 150 pounds in raising it to a height of 10 feet?

3. A man raises a certain mass to a height of 4 feet and in so doing he performs 360 foot pounds of work. How great is the mass?

4. What is the energy of a bullet whose mass is 10 grams, when its velocity is 35,000 cm. per second?

5. An iron ball whose mass is 50 pounds moves at the rate of 6 feet per second. Compute its kinetic energy.

6. A ten-pound shot has a velocity of 1800 feet per second. If it struck a target at this instant, how much work would be done by the target in stopping it?

7. If a certain mass moves for a distance of 1 meter against a constant resistance of 12 dynes, how many ergs of kinetic energy had it at the start?

8. A body has 3200 ergs of kinetic energy, and moves against a constant resistance of 8 dynes. How far will it move?

9. How much work is done in raising a mass of 5 kilograms to a height of 2 meters?

10. If a constant force of 75 pounds acts upon a body through 15 feet of space without wasted work, how much energy does it give to the body?

11. Find the kinetic energy of a 200-ton train whose velocity is 30 miles an hour.

12. A moving body has 3 foot pounds of kinetic energy and its mass is 7 pounds. What is its velocity at that instant?

13. Compute the kinetic energy of a stone whose mass is 40 kilograms, if its velocity is 5 meters per second.

14. A boy pushes upon a cart with a force of 20 pounds through a space of 12 feet. If one third of his work is wasted meantime in overcoming resistance, how much energy does he finally give to the cart?

Machines. Page 109

In using the law of machines it is not always easy to determine how far the force and the resistance may act, but by a little thought in each case we may discover some means of finding the ratio of these two distances to each other. For example: in levers the length of the two arms are in the same ratio as the spaces traversed by the points of application of F and R; in the wheel and axle the respective radii or diameters bear the same ratio as S and S'; etc.

PROBLEMS

1. How great a force, 5 cm. from the fulcrum of a lever, will balance a force of 30 grams applied 20 cm. from the fulcrum?

2. A crowbar is 150 cm. long and is so used that the fulcrum is 10 cm. from one end. As that end moves through 2 inches of space, how far does the other end move?

3. A certain wheel is 12 inches in diameter and its axle is 1 inch in diameter. If a force of 7 pounds is applied to the rim of the wheel, what resistance at the axle will balance it?

4. If a force of 25 pounds is exerted on the handles of a pair of nippers at a point 8 inches from the hinge, how much force will be exerted by the jaws at a point one half inch from the hinge?

5. Using a single movable pulley, a man holds a 196-pound barrel of flour off the floor. Disregarding waste, how much force does he exert?

6. A gear wheel having 44 teeth runs upon another that has 11 teeth. How much faster does the second run than the first? A force of 28 pounds applied to the first would overcome what resistance applied to the second?

7. A wedge is 24 cm. long and 3 cm. thick at its base. A blow of 35 pounds will drive it into wood so as to exert what force sidewise?

8. If a crowbar is used so that its fulcrum is 4 inches from one end, how far from this fulcrum must a force of 20 pounds be applied in order to move a mass of 240 pounds applied at the near end?

9. The threads of a screw are one sixteenth of an inch apart. In driving this screw force is applied to the handle of a screw-driver 3 inches in circumference. If this force is 5 pounds, how great resistance will the screw overcome?

10. A bicycle wheel is 88 inches in circumference. If the large sprocket wheel has 24 teeth and the small one has 8 teeth, how far will the bicycle move during one revolution of a pedal?

11. What force will be needed to roll a cask weighing 250 pounds up a plank 15 feet long to a wagon whose bottom is 3 feet from the ground?

12. A horse pulling with a force of 200 pounds can overcome how great a resistance if 3 movable pulleys are used?

13. The handle of a vice describes a circle 5 feet in circumference while the jaws move one quarter inch nearer together. With how great force will a body be nipped if a pull of 10 pounds be applied at the end of the handle?

14. A small gear wheel of 12 teeth runs in a larger wheel of 84 teeth. A force of 5 grams applied to the smaller would overcome how much resistance applied to the larger wheel? How much farther would the force move than the resistance?

15. Two boys carry a 24-pound basket of apples hung on a pole between them. If the basket is 2 feet from one boy's shoulder and 3 feet from the other's, what weight does each bear? Disregard the weight of the pole.

16. A 12-foot plank weighs 30 pounds. If, with one of its ends on the ground, we support it at a point 2 feet from the other end, how great a weight would we bear?

THERMOMETER. PAGE 130

Since between the freezing temperature and the boiling temperature of water there are (100° − 0°) 100 Centigrade degrees, or (212° − 32°) 180 Fahrenheit degrees, it is evident that one Fahrenheit degree is worth $\frac{100}{180}$ or $\frac{5}{9}$ of a Centigrade degree; also one degree Centigrade is equal to $\frac{180}{100}$ or $\frac{9}{5}$ of a Fahrenheit degree. These values, together with the fact that 0° F. is 32 Fahrenheit degrees colder than 0° C., may enable us to change readings from one scale to the other.

To change a Centigrade reading to Fahrenheit, multiply the number of degrees by $\frac{9}{5}$ and add 32°.

To change a Fahrenheit reading to Centigrade, subtract 32 from the number of degrees and multiply the result by $\frac{5}{9}$. Care must be used to subtract the 32° according to the methods of algebra in the case of negative (−) numbers.

PROBLEMS

1. How many Centigrade degrees are there between 23° C. and − 12° C.? How many Fahrenheit degrees?

2. How many Centigrade degrees are there between − 8° F. and − 44° F.?

3. Change these Centigrade readings to Fahrenheit readings: 50°; − 10°; − 45°; 65°; 30°; − 20°; − 15°; 0°; 4°; − 39°.

4. Change these Fahrenheit readings to Centigrade readings: 104°; 50°; 23°; − 13°; 176°; 5°; 32°; − 31°; 212°; − 39°.

5. On the Réaumur scale the freezing point is marked 0° and the boiling point 80°. Devise a method for interchanging Centigrade and Fahrenheit readings with those of the Réaumur scale.

Quantity of Heat. Pages 133 and 134

PROBLEMS

1. How much heat will be required to raise 4 kg. of water to 100° C. if its temperature is 40° C.?

2. If the specific heat of iron is .113, how much heat will raise a 2-kilogram mass of iron to a temperature of 300° C. from 20° C.?

3. How much heat will raise the temperature of one liter of water from the melting point to the boiling point?

4. If the melting point of lead is 326° C. and its specific heat is .031, how many calories of heat will be used in raising 10 kg. of lead to its melting point from 18° C.?

5. If the quantity of heat that will raise 5 kg. of water from 0° to 100° were applied to the same mass of iron at 0°, to what temperature would the latter be raised?

6. If the specific heat of alcohol is .597, to what temperature will 1 kg. of alcohol be raised by 12 calories of heat?

7. A piece of iron weighing .5 kg. loses how much heat in cooling from 100° to 10° C.?

Latent Heat. Page 159

The number of calories of heat required to melt one kilogram of a solid is called the *heat of fusion* of that substance. It has been found by experiment that *80 calories* of heat are used in melting one kilogram of ice without producing any rise in its temperature.

The *heat of vaporization* of a liquid body is the number of calories required to change one kilogram of it to a gaseous state. In changing water to steam nearly *536 calories* of heat are required for every kilogram of the liquid.

PROBLEMS

1. How much heat is required to melt 5 kg. of ice?

2. In changing to steam 3 liters of water, how much heat is needed?

3. How many calories of heat are given off when 10 kg. of water freezes entirely? How much heat is given off when one kilogram of water is condensed from steam?

4. How much mechanical work (in kilogram meters) might be done by the heat used in converting one liter (about a quart) of water into steam?

5. What weight of water at 40° C. will just melt 3 kg. of ice at 0° C.?

Sound. Pages 181 and 195

PROBLEMS

1. Compute the velocity of sound waves in air at 37° C.

2. In air at 17° C. how far will sound waves travel in 4 seconds?

3. Compare the velocity of sound waves in the air of summer and of winter, assuming a summer temperature of 77° Fahrenheit and a winter temperature of 15° Fahrenheit.

4. Suppose you see smoke from a distant gun and in 6 seconds hear the noise of the explosion. If the temperature is 20° C., how far away is the gun?

5. The moon is about 240,000 miles away. If the space between us and the moon were full of air at the ordinary temperature, and sound waves from an explosion there could reach us, how long would they be in coming?

6. A wooded hill 2180 feet away sends back to us an echo. If the air has a temperature of 32° F., how much time elapses between one pistol shot and its echo?

7. A tuning fork vibrates 110 times per second. If the temperature is 0° C., how long is each wave?

8. In air at 16° C. what is the length of each wave when middle *C* is sounded?

9. What is the vibration rate of the octave above middle *C*? Find the vibration rate of a tone 3 octaves below middle *C*.

10. The wave length of a certain tone in air at 16° C. is eleven feet. What is the vibration rate of the tone?

11. The vibration rates of the different tones of the diatonic scale (*C*, *D*, *E*, *F*, *G*, *A*, *B*, *C*) are related to that of middle *C* as follows: 1, $\frac{9}{8}$, $\frac{5}{4}$, $\frac{4}{3}$, $\frac{3}{2}$, $\frac{5}{3}$, $\frac{15}{8}$, 2. Find the vibration rate of each tone.

12. Find by the aid of some familiar musical instrument the lowest and the highest tone that you can sing, and compute the vibration rate of each.

13. Compute the wave length of the lowest and of the highest tones that can ordinarily be heard, the air having a temperature of 32° F.

14. A certain string vibrates 33 times per second. Find its tone.

15. If the air had a uniform temperature of 5° C., how long a time would be required for sound waves to go once around the earth, allowing 25,000 miles for the earth's circumference?

Light. Pages 217 and 218

PROBLEMS

1. How far will light waves travel in one minute?

2. Compute the time required by a light wave to make one journey around the earth — 25,000 miles.

3. Compute the time required by light waves in coming to earth from the sun, the average distance being 93,000,000 miles.

4. Express in miles the distance of a star that is four light years distant.

5. How does the intensity of illumination on a page held 2 feet from a lamp compare with that on a page held 3 feet from the same lamp?

6. If the planet Neptune is 30 times as far from the sun as we are, how would the brightness of sunlight there compare with the sun's illumination here upon earth?

Electricity. Pages 317–319

PROBLEMS

1. A current flowing through a silver nitrate solution deposits 20.124 grams of silver in one hour. What is the current strength?

2. How many grams of silver would be deposited by a current of 12 ampères in 15 minutes?

3. If 10 coulombs of electricity pass a point in a conductor in one second, what is the current strength? Supposing the same quantity of electricity passes the point in 4 seconds, how great is the current strength?

4. If a current of 3 ampères flows through a conductor for 30 minutes, how much electricity is transferred by the current?

5. Find the electrical power of a current of 2 ampères at a pressure of 3 volts. (See § 333. To find the power, or number of watts, multiply the number of ampères by the number of volts. Thus, watts = ampères × volts.)

6. Find the rate at which work will be done by a current of 12 ampères at a pressure of 20 volts.

7. If the power of a current is 50 watts and its strength is 8 ampères, what is the E.M.F. of the current?

8. A current at a pressure of 110 volts has a power of 440 watts. What is its current strength?

9. A current of 1 ampère is maintained against a resistance of 6 ohms. What is its E.M.F.? (See § 334.)

10. If a current of 5 ampères requires an electro-motive force of 60 volts to maintain it, what is the resistance of the conductor?

11. If a pressure of 8 volts maintains a current against a resistance of 10 ohms, what is the current strength?

12. The resistance of a certain lamp is 50 ohms. How great a pressure will be required to maintain a current of 1.5 ampères through it?

13. A cell of 2 volts electro-motive force rings a call bell. If the resistance of the circuit is 3 ohms, what is the strength of current?

14. In order to maintain a current of $\frac{3}{4}$ ampères through a certain coil an E.M.F. of 9 volts is needed. What is the resistance of the coil?

15. Find the E.M.F. that will be required to maintain a current of 50 ampères against a resistance of 10 ohms.

16. How great a current can be maintained by a pressure of 1000 volts through a conducting circuit that offers a resistance of 250 ohms?

Table of Approximate Equivalents

1 inch	= 2.54 cm.	1 sq. mi.	= 2.59007 km.^{2}
1 foot	= 30.48 cm.	1 cu. in.	= 16.3871 cm.^{3}
1 yard	= 0.9144 m.	1 cu. ft.	= 0.02832 m.^{3}
1 mile	= 1.60935 km.	1 quart	= 0.9464 l.
1 sq. in.	= 6.4516 cm.^{2}	1 gallon	= 3.7854 l.
1 sq. ft.	= 0.0929 m.^{2}	1 grain	= 0.064799 g.
1 sq. yd.	= 0.83612 m.^{2}	1 ounce (av.)	= 28.3495 g.

1 pound (av.) = 0.4536 kg.

APPENDIX B

Boyle's Law

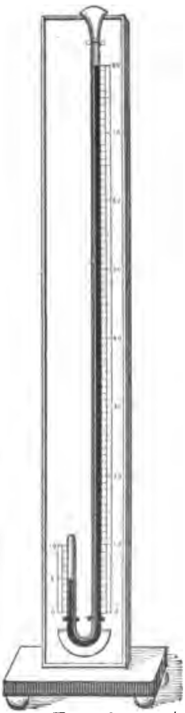

Fig. 234

Since gaseous bodies have no volume except as they are confined from without, it is evident that their volumes vary greatly with external conditions. These conditions and their relation to volume are summed up in the statement called Boyle's (or Mariotte's) Law: The temperature being constant, the volume of a body of gas varies inversely with its density and elasticity, and the pressure upon it.

This law may be demonstrated by means of the tube, closed at one end, shown in Fig. 234. Pour mercury into the tube until it stands at the same level in both arms, the gas above the mercury in the closed portion being now at the same pressure and density as the atmosphere in the open end. Note the points on the scale at which the mercury levels stand. Now pour mercury into the long arm till it rises through a few divisions on the scale — say 10. Make a note of this number; opposite this on paper note the decrease in volume of the gas inclosed in the other arm. Now double the pressure by pouring in more mercury until its height

above the original level in the long arm is twice as great — say 20 divisions on the scale. Again note this number and also the further decrease in volume of the gas in the short arm. Similarly add more mercury, noting the increase of pressure and the decrease of volume in each case. Compare these results with reference to Boyle's Law.

It is important to note that the law is only approximately true, as different gases are subject to different laws of compressibility.

Static Electricity

Electrophorus. — A device for experiment with induced electrical charges, called an electrophorus, may be made as follows. Fill a shallow metal plate with wax; in the center of another flat plate of metal fix an insulating handle. Now if the surface of the wax be rubbed with fur, a negative charge will be developed there. Bring the other metal plate down lightly upon the wax; it will now be charged by induction from the negative charge on the wax, its lower surface being positively electrified and its upper surface (farther from the wax) negatively charged. If now this upper surface of the metal plate is touched, the negative charge passes into the body of the one who touches it and so to the earth. Remove the finger and lift the plate; when at a little distance from the wax the positive charge that was on its lower surface is released and spreads over all the surface of the metal. Now present a finger tip to the edge of this plate; when it is very near a spark may be seen to pass from one to the other.

Several machines which employ this principle have been devised and are used to develop greater charges than is commonly done with the electrophorus.

Leyden Jar. — The charges developed by these electrical machines may be withdrawn from them and stored for a time by means of condensers. In these a considerable charge may be collected. The common form of condenser is called the Leyden jar. It is a glass jar covered outside and inside for about two thirds of its height with a coating of tin foil. A stopper of some insulating material is pierced in the middle by a brass rod; this generally ends in a brass knob outside, and is connected with the tin foil coating inside by a conductor — *e.g.* a metal chain. The jar may be charged by bringing the knob in contact with the charged portion of an electrical machine, while the outer tin foil covering is connected by some conductor with the earth. From the machine the charge passes to the inner surface of the glass by conduction. The inner and outer surfaces of the jar will now be oppositely charged. To discharge the jar, simply connect the outer coating with the knob by some conductor. This may be done by holding the jar in one hand, by its outer coating, and touching the knob with the other hand; the discharge is made through the body and a shock is felt. Commonly a bent wire is used; it may have an insulated handle. If the wire touches the outer tin foil and is near, but not touching, the knob, a spark may pass between it and the knob. This is similar to lightning on a very small scale.

SOME NOTED SCIENTISTS

This list includes the names of men who have been associated with the growth of scientific knowledge and useful invention. No attempt has been made to mention all who are famous, or to sum up the whole of each man's life work.

The names have been selected from a list prepared by Mr. H. Carrington Bolton, Washington, D.C.

AAHMES (about 1700 B.C.): Egyptian. Author of the earliest recorded book on mathematics.

ALBERTUS MAGNUS (1193–1280): most able scholar of the Middle Ages.

AMPÈRE, A. M. (1775–1836): French physicist. Noted for his researches and discoveries in electro-magetism.

ANAXIMANDER (610–547 B.C.): Greek philosopher and scientist. He held the idea that the universe as a whole was unchangeable.

ARCHIMEDES (287–212 B.C.): Sicilian. Most renowned mechanician of ancient time; discovered the principle of the buoyancy of fluids.

ARISTOTLE (384–322 B.C.): Greek philosopher of note. Said to have discovered the shape of the earth by studying lunar eclipses.

BACON, ROGER (1214–1294): English. In his writings he anticipated many scientific discoveries; said to have invented gunpowder.

BELL, ALEXANDER GRAHAM (1847–): American scientist. Invented the telephone.

BERNOUILLI, DANIEL (1700–1782): Swiss physicist and astronomer; published works on hydraulics and mechanics.

BERZELIUS, J. J. (1779–1848): Swedish chemist. Effective in introducing new methods; worked on metals.

BLACK, JOSEPH (1728–1799): Scotch chemist. Discoverer of latent heat.

BOYLE, ROBERT (1627–1691): Irish philosopher. Researches in the properties of gases.

BRADLEY, JAMES (1693–1762): English astronomer. Discoveries connected with the aberration of light.

BRAHE, TYCHO (1546–1601): Danish philosopher. He laid the foundation for practical astronomy.

BREWSTER, SIR DAVID (1781–1868): Scotch physicist. Researches in light. He did much to popularize the study of natural science.

BUNSEN, ROBERT WILHELM (1811–1899): German chemist. Inventor of many important aids to scientific research.

CAVENDISH, HENRY (1731–1810): English physicist and chemist. Earliest experimenter in several important branches of chemistry.

CELSIUS, ANDERS (1701–1744): Swedish astronomer. First to use a centigrade scale.

CHARLES, J. A. (1746–1823): French. Made first hydrogen balloon; famous for his experiments with gases.

COPERNICUS, NIKOLAUS (1473–1543): Polish mathematician. First to expound the present theory of the planetary system.

CROOKES, SIR WILLIAM (1832–): English physicist and chemist. His experiments with electric discharges in rarefied gases are famous.

DAGUERRE, LOUIS J. M. (1789–1851): French. His researches developed the daguerreotype, which led to modern photography.

DALTON, JOHN (1766–1844): English chemist. Author of the atomic theory.

DANIELL, J. F. (1790–1845): English physicist. He invented the constant battery.

DAVY, SIR HUMPHRY (1778–1829): English chemist. Discovered several elements; invented the miner's safety lamp; made important researches in chemistry.

DESCARTES, RENÉ (1596–1650): French philosopher. One of the founders of modern philosophy.

Dewar, James (1842–): English physicist, noted for his experiments in low temperatures.

Edison, Thomas A. (1847–): American inventor. He has invented or improved many important electrical devices and others of commercial value; inventor of the phonograph.

Euclid (300 B.C.): Alexandria. Celebrated mathematician.

Fahrenheit, G. D. (1686–1736): German physicist. He made improvements on the thermometer and experimented in hydraulics.

Faraday, Michael (1791–1867): English physicist. Several important electrical discoveries were made by him, notably the laws of induction and electrolysis. Devised the first electric motor.

Franklin, Benjamin (1706–1790): American statesman and scientist. Made many practical inventions; also showed that lightning and electricity are related.

Fraunhofer, Joseph von (1787–1826): Bavarian optician. First determined the dark lines in the solar spectrum; measured wave lengths of light waves.

Fresnel, Augustin J. (1788–1827): French physicist. Researches in light; also in its use in lighthouses.

Galilei, Galileo (1564–1642): Italian philosopher. Experimented with falling bodies and the pendulum. He was the first to use a telescope in studying the heavens.

Galvani, Luigi (1737–1798): Italian physician. He discovered some physiological effects of electricity and worked on the electric battery in connection with Volta.

Gay-Lussac, J. L. (1778–1850): French chemist. Experimented in terrestrial magnetism and the expansion of gases; made the first balloon ascension for scientific purposes.

Gilbert, William (1540–1603): English physicist. He made the first careful study of magnets and static electricity.

Grove, Sir William (1811–1896): English physicist. Researches in electricity and electric generators.

Guericke, Otto von (1602–1686): German physicist. He invented the air pump and experimented with gases.

Halley, Edmund (1656–1742): English astronomer. Studied terrestrial magnetism.

HELMHOLTZ, HERMANN VON (1821–1894): German physiologist and physicist. He made valuable researches in sound and optics.

HENRY, JOSEPH (1797–1878): American scientist. His researches resulted in important discoveries in electro-magnetism.

HERON (about 250 B.C.): Alexandria. He invented several ingenious devices, among them a compressed-air fountain and a sort of heat engine.

HERSCHEL, SIR WILLIAM (1738–1822): English astronomer. Improved the telescope and made important astronomical discoveries.

HERTZ, HEINRICH (1857–1894): German physicist. Researches begun by him in electrical waves have developed into important modern study, resulting in wireless telegraphy, etc.

HIPPARCHUS (160–125 B.C.): Greek astronomer. He was the first to classify the stars; solved triangles and made other contributions to mathematical science.

HUMBOLDT, ALEXANDER VON (1769–1859): German scientist. In a long life of travel he made many valuable contributions to botany, physiography, physics, and astronomy.

HUYGENS, CHRISTIAN (1629–1695): Dutch scientist. Invented the pendulum clock and balance-wheel watch; devised valuable mathematical methods; made important discoveries in polarization of light.

JOULE, JAMES P. (1818–1889): English physicist. He was the first to actually determine the mechanical equivalent of heat.

KELVIN, LORD (1824–   ): eminent British physicist. Renowned for researches in the composition of matter, as well as for numerous discoveries in several branches of physics.

KEPLER, JOHANN (1571–1630): German astronomer. Renowned for his valuable researches; discoverer of the laws of planetary motion.

KIRCHHOFF, GUSTAV ROBERT (1824–1887): German physicist. His discoveries led to the invention of spectrum analysis.

LANGLEY S. P. (1834–   ): American scientist. Renowned for his many researches; experiments with the aërodrome.

LAPLACE, PIERRE S. (1749–1827): French scientist. His work in physics and astronomical mathematics places him second only to Newton in that branch of science.

LAVOISIER, A. L. (1743–1794): French scientist of note. He studied color and weights and measures; also he was first to apply science to husbandry.

LEIBNITZ, GOTTFRIED (1646–1716): German philosopher and scientist. He did more than any other man to bring scientific knowledge of his time into a unit.

LIEBIG, JUSTUS VON (1803–1873): German chemist. Noted for his studies of fermentation and decay. He labored to apply chemistry to the needs of everyday life.

MARCONI, GUGLIELMO (1875–): Italian inventor. Famous for his valuable work in wireless telegraphy.

MARIOTTE, EDME (1620(?)–1684): French physicist. Noted for his experiments with gases.

MAXWELL, J. CLERK (1831–1879): English physicist. Studied electro-magnetism and also made valuable researches in the theory of heat and radiant energy.

MORSE, S. F. B. (1791–1872): American artist. Famous for his labors which produced the telegraph.

NEWCOMB, SIMON (1835–): most eminent of American astronomers.

NEWTON, SIR ISAAC (1642–1727): English philosopher and mathematician; greatest of natural scientists. He formulated the laws of motion and the law of gravitation; discovered law of refraction and made numerous valuable contributions to scientific knowledge.

OERSTED, HANS C. (1777–1851): Danish physicist. His important discovery of the magnetic effect of electric currents first showed the relation of magnetism to electricity.

OHM, G. S. (1787–1854): German physicist. He established the law which forms the basis for mathematical work in electricity.

PAPIN, DENIS (1647–1712): French physicist. About 1690 he proposed steam for motive power and described a rude steam engine.

PASCAL, BLAISE (1623–1662): French author. Experimented with gases and studied pressure in fluids.

PASTEUR, LOUIS (1822–1895): French chemist. Discovered that fermentation is caused by living organisms; his researches developed valuable results.

PRIESTLEY, JOSEPH (1733–1804): English scientist. His discovery of oxygen in 1774 marks an epoch in the science of chemistry.

PTOLEMY (70–147): Alexandrian astronomer. He first catalogued the stars, naming forty-eight of the constellations; knew something of refraction.

PYTHAGORAS (582–500 B.C.): Greek philosopher and mathematician of some note.

RÉAUMUR, RENÉ (1683–1757): French scientist. Invented the Réaumur thermometer used in parts of Europe.

REGNAULT, HENRI (1810–1878): French scientist. He investigated the application of heat to compressed gases.

RÖMER, OLAF (1644–1710): Danish astronomer. Noted for his researches; he was the first to measure the velocity of light waves.

RÖNTGEN, WILHELM K. (1845–): German physicist. Famous for his discovery of the so-called X-ray; also for researches in heat and optics.

RUHMKORFF, HEINRICH D. (1803–1877): German scientist and inventor.

RUMFORD, COUNT (1753–1814): American. Famous, as a scientist, for his researches in the subject of heat.

SAUVEUR, JOSEPH (1653–1716): French mathematician. Established the science of musical acoustics.

TESLA, NIKOLA (1857–): Austrian electrician. He has made important contributions to practical electricity, notably in connection with alternating currents.

THOMSON, SIR WILLIAM: see Lord Kelvin.

TORRICELLI, EVANGELISTA (1608–1647): Italian mathematician. Inventor of the barometer.

TYNDALL, JOHN (1820–1893): British physicist. Noted for his researches in physics, particularly concerning the molecular constitution of matter.

VOLTA, ALESSANDRO (1745–1827): Italian physicist. His discoveries led to the electric generator called the voltaic cell.

WATT, JAMES (1736–1819): British inventor. He developed the steam engine and made many improvements upon it.

WHEATSTONE, SIR CHARLES (1802–1875): English physicist and inventor of several improvements in the telegraph. He also studied magnetism, optics, and sound.

YOUNG, THOMAS (1773–1829): English physicist. He discovered the law of the interference of light and was the first to suggest the present theory of color vision.

GLOSSARY

The explanations here given apply to the word as it is used in the text. No attempt has been made to give all the meanings of any word. Many words not herein contained are explained fully in the text. The student may easily find such explanations by use of the Index.

Absolute: complete in itself, unlimited, entire.

Absorb: to take in; *e.g.* a sponge absorbs water.

Adjacent: touching one another.

Alter: to change, to make over.

Amalgam: a peculiar alloy which mercury makes with other metals.

Analysis: the separation of anything into the several parts which compose it. Chemists *analyze* compound substances by separating the various elements of which they are made.

Angle: a figure formed by the meeting of two lines or planes. A *right angle* is formed when the distance between the lines is 90 degrees, or one quarter of a circle. An *acute angle* is one which is less than 90 degrees. An *obtuse angle* is greater than 90 degrees.

Application: use; the way in which a principle is used is called its application.

Approximate, -ly: nearly; almost but not quite exact.

Articulation: the formation of words in speaking.

Artificial: made by man's craft or devices.

Astronomy: the science of the celestial bodies,—stars, planets, etc.

Attract: to draw to, to cause to approach.

Attraction: the tendency to draw, the act of drawing or alluring.

Auditory: relating to hearing or to the ear.

Balance: (as a verb) to counteract the power of one force with an equal one; to produce an equilibrium of forces.

Bore: the internal diameter of a cylindrical tube, pipe, or gun barrel.

Brittle: fragile; easily broken by a blow or by lateral pressure.

Cartilage: a tough animal tissue found in the ear, nose, throat, and on the ends of bones.

Centigrade: a kind of thermometer scale. The word means one hundred steps.

Chemistry: the science of the structure or composition of matter.

Circumference: the line surrounding a circular figure.

Classify: to arrange in groups with reference to some common feature.

Combine: to unite, to bring together; (in chemistry) to unite two or more substances into one.

Compact: closely crowded together.

Comparative, -ly: considered with reference to something else.

Compress: to crowd into a smaller space.

Compute: to reckon, to count up.

Concave: curving inward; an incurving surface.

Conform: to accord or agree with.

Consequent: following as a natural or logical result.

Constant: always the same, steady, unchanging.

Constantly: uniformly, unvarying, regularly.

Constitute: to compose, to form, to make up.

Consume: to destroy by decomposition, as by fire or by decay.

Contact: touch, direct connection.

Continuous: unbroken, uninterrupted. A constant succession without a break is implied in the word *continuous*, whereas *continual* implies a succession with possible interruptions at regular intervals.

Control: (noun) the power to govern or regulate; (verb) to govern, to regulate.

Convert: to change from one condition or state to another.

Convex: curving or bulging outward.

Create: to bring into existence.

Cross section: the end of a body which has been made by cutting it across at right angles to its length.

Cylinder: a rollerlike body whose cross section is a circle, of uniform diameter at all points along its length.

Cylindrical: shaped like a cylinder.

Damper: in pianos a device to prevent the strings from vibrating longer than the player desires.

Decohere: to cease cohering (*i.e.* clinging together).

Decompose: to break up into its parts; (in chemistry) to separate a compound substance into its elements.

Decrease: to grow smaller, to diminish.

Definite: fixed, exactly determined, clearly defined.

Degree: one of a succession of grades in quality, rank, or position; the several steps or markings of a thermometer scale; a unit for measuring angles and arcs. A circle contains 360 degrees, and each angle may be measured by the bit of circumference included in its sides, provided the vertex of the angle be at the center of the circle.

Demagnetize: to lose the magnetic property; to destroy the magnetic property in a body.

Depression: a sunken spot; an incurving irregularity on a surface.

Detail: a very minute portion, a specific part.

Detect: to find out; to discover (used when the discovery is difficult or delicate).

Device: a tool or instrument designed for a certain use.

Diffuse: to spread about, to circulate.

Diffusion: a property of gases whereby they tend to expand and mix with other gases indefinitely.

Discover: to find out.

Distinct: separate, marked, having some peculiar feature.

Distinguish: to tell one from others.

Domain: scope, extent.

Electrification: (noun) the condition of being charged with static electricity; the process of charging a body electrically.

Electrified: electrically charged.

Element: the word is sometimes applied to the plates of a voltaic cell; chemical use defined on page 147.

Enlarge: to make larger.

Equivalent: having equal value but not necessarily of the same kind.

Evident, -ly: easy to be seen, very apparent.

Exception: something not included in a certain statement; an exclusion, an objection or irregularity.

Experiment: a trial; in scientific study a method of determining certain results by actual tests.

Fibrous: composed of fibers, or of a threadlike structure.

Flexible: easily bent, pliable; the opposite of rigid.

Formula: an established rule, an arranged form to be used in computations.

Generate: to produce, to originate, to bring into being.

Generator: in electricity a device for producing electrical energy, especially a dynamo or battery.

Gradual: by slow or easy steps.

Horizontal: level, parallel to the plane of the horizon, perpendicular to a vertical line.

Hydraulic: relating to conveyance of pressure by water.

Hydrogen: a gas, — the lightest known. Hydrogen unites with oxygen to form water.

Image: a picture or likeness of an object.

Immerse: to dip into a liquid, to completely cover.

Impenetrable: cannot be penetrated or entered.

Imprison: to entirely shut up, to confine.

Impurity: any foreign substance unlike the body in which it may occur.

Indefinite: not clear or exact, vague, uncertain.

Indestructible: cannot be entirely destroyed.

Individual: any one person or thing considered apart from others.

Infinite: incalculable; beyond the power of human reason to understand.

Inflate: to fill up, with air or any gas.

Influence: (verb) to control, to affect; to partially control.

Inker: in telegraphy a device for translating the long and short electric impulses into dashes and dots on paper.

Intelligible: clear, capable of being understood.

Intensity: a great degree of force or power, etc.

Intersect: to cut across.

Interval: a period of time or space between two events or things.

Intricate: difficult, involved, hard to follow.

Inversely: opposite in relation. To say that one thing "varies inversely" as another means that as one increases, for example, the other decreases, the rate of increase and decrease being the same.

Invisible: imperceptible, not capable of being seen.

Jacket: cylinders are sometimes surrounded by a hollow compartment in which cold water is kept running, to keep the cylinder cool. The name also applies to packing around a pipe or retort to prevent loss of heat.

Junction: a joint.

Kilogram-meter: a unit of work; the work done in raising one kilogram to a height of one meter.

Laboratory: a workshop devoted to scientific research.

Level: horizontal; every point equally distant from the center of gravity of the earth.

Luminous: giving forth light from itself.

Material: relating to matter; the substance of which a body is made.

Mechanical: relating to various applications of motion, or means for causing or using motion.

Media: plural of medium.

Medium: a body or substance through which any effect is carried from one place to another.

Membrane: any thin layer of animal or vegetable tissue.

Mercury: a heavy metallic liquid sometimes called quicksilver.

Metallic: relating to metals.

Modify: to change in some particular.

Negative: the opposite of positive; used sometimes to denote absence of any quality or quantity.

Neutral: neither one thing nor its opposite, neither positive nor negative; indifferent, undecided.

Neutralize: to make neutral by meeting any effect with an equal degree of its opposite effect; to destroy some characteristic feature.

Non-conductor: a substance which will not conduct.

Normal: conforming strictly to the common rules or laws; (noun) the perpendicular to a line.

Observe: to see and make note of.

Octave: in music the eighth tone above or below another.

Optic: relating to the sense or organ of sight.

Orbit: the path of a moving body revolving about another; the path of a planet as it moves about the sun; the bony socket in which the eye rests.

Ordinary: common, usual.

Organs: the various parts of the animal body which perform a special service. The eye, ear, etc., are called sense organs.

Origin: the earliest beginning or the source of anything.

Originate: to devise or make for the first time.

Oxygen: a gas found in air, water, and earth. It supports combustion and is necessary to animal life.

Parallel: said of two or more lines or surfaces which are at all points equally distant.

Partial, -ly: not wholly.

Particle: any very small bit of matter.

Permanent: lasting, enduring.

Phenomenon: any occurrence in nature, particularly such as are unusual or marked.

Physicists: those devoted particularly to the study of physical science.

Plane: a surface which is perfectly smooth and flat. A true plane has no thickness and hence exists only in theory; such a plane extends indefinitely in length and width.

Platinum: a very heavy metal, not easily affected by heat and most chemicals.

Preceding: coming before.

Produce: to bring forth, to make.

Projection: any irregularity extending outward from a surface.

Prominent: noticeable, in plain sight.

Rapidity: speed, quickness of motion.

Rare: not common, not plentiful.

Receptacle: any dish, box, or other place to receive things.

Rectangle: a figure whose four angles are right angles and whose sides are straight lines.

Require: to need, to demand.

Reservoir: any tank, pond, or cavity used as a storage for large quantities of water or other liquid.

Resistance: opposition.

Retain: to hold or keep possession of.

Reversed: turned exactly around.

Rotary: turning about a fixed point or line as an axis.

Salt: a chemical compound formed usually by the union of a metal with an acid.

Satisfactory: fulfilling all needs or demands.

Sensation: the effect of any outside condition upon a sense organ.

Sensitive: very easily affected.

Similar: having many points of likeness, though not exactly the same in every way.

Source: origin, first cause.

Specific: having some definite relation.

Spherical: shaped like a sphere or ball, globular.

Stationary: fixed, not moving, not movable.

Substance: structure; the material of which a body is composed.

Suspend: to hang, to support from above.

Tension: the state of being strained or pressed out of a normal shape or condition.

Thorough, -ly: carefully and completely.

Transfer: to bear from one to another.

Transform: to change in form, state, kind, etc.

Transmission: conveying through any medium.

Transmit: to serve as a medium through which anything or any impulse may be borne.

Unaided: without help.

Vapor: the gas of such substances (water, alcohol, etc.) as change from a liquid to a gas at comparatively high temperatures.

Vertical: parallel to a plumb line; (noun) a straight line whose direction is toward the center of gravity of the earth.

Visible: perceptible, capable of being seen.

Vitiated: a word applied to describe air from which the oxygen has been removed, to an extent which makes it unfit to be breathed.

Volatile: easily evaporated or changed into a gas.

LIST OF ABBREVIATIONS USED IN THE TEXT

C.	Centigrade.	g.	Gram, or grams.
cc.	Cubic centimeter, -s.	*i.e.*	That is.
c.g.	Center of gravity.	kg.	Kilogram, -s.
cg.	Centigram.	km.	Kilometer.
cl.	Centiliter.	l.	Liter.
cm.	Centimeter.	l.d.	Line of direction.
dg.	Decigram.	m.	Meter, -s.
dl.	Deciliter.	mg.	Milligram.
dm.	Decimeter.	ml.	Millileter.
e.g.	For example.	mm.	Millimeter.
E.M.F.	Electro-motive force.	sp.gr.	Specific gravity.
etc.	And so forth.	$\times$	Multiplied by.
F.	Fahrenheit.	$\Leftrightarrow$	Is equivalent to.

INDEX

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ANNOUNCEMENTS